SECTION 3

ELECTROMECHANICAL UNITS

Most of the units in this section are divided into two groups:

a. Follow-up controls

b. Synchros

These two groups of units correspond to the two main types of jobs for which mechanical computers generally call upon the help of electricity:

a. One of these jobs is positioning mechanisms and lines of gearing quickly and accurately against loads which are too great for mechanism outputs alone to handle. Electric motors called "servos" are put into the computers and range keepers at points where additional torque is needed. These motors must be accurately controlled. To provide the necessary control a variety of devices has been developed called "follow-up controls."

b. The other main use for electricity in mechanical computers is to provide automatic reception and transmission of information. The electrical unit which is used for this purpose is called a "synchro." Sending information from one synchro to another is called "synchro transmission."

MAGNETISM and ELECTRICITY

The larger mechanical computers contain several different kinds of electromechanical mechanisms such as servo motors, synchros, and solenoid locks and clutches. It is necessary to know the basic principles of magnetism and electricity to understand how they work. This chapter is confined mainly to the facts about electricity and magnetism which will be of practical use in understanding and maintaining basic Ford electromechanical units.

Magnetism

In ancient times the Magnesites, a Greek tribe, noticed that certain pieces of iron ore attracted iron and other materials.

The iron pieces that had the power to attract became known as magnets in honor of the people who had discovered them.

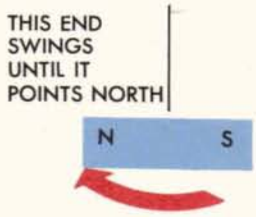
Later it was learned that it was possible to make artificial magnets from other pieces of iron or steel by stroking them with a natural magnet several times in the same direction. Then it was no longer necessary to search for natural magnets. Man could make his own.

Modern artificial magnets have many uses in fire control systems.

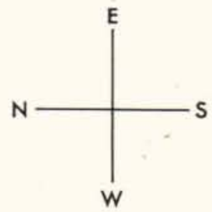
Magnetic poles

A bar magnet is a bar of steel that has been magnetized. If a bar magnet is placed in a dish of iron filings, some of the filings will cling to the bar when it is taken out of the dish. Most of the filings will cling to the ends of the bar with only a few around the center portion.

Magnetic strength is greater near the ends of the bar. The ends of the bar are called the *poles* of the magnet. Every magnet has two poles. One is known as the North pole, and is usually shown as *N* on a diagram. The other pole is known as the South pole, and is marked *S*.

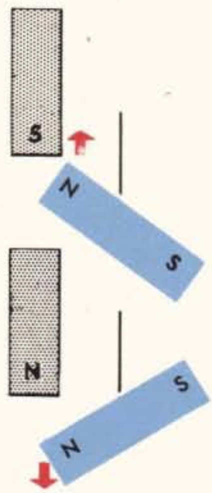


If a magnet is suspended horizontally so that it is free to move, it turns slowly until one end points north. No matter how often the magnet may be swung away from this position, this same end of the magnet always returns and points north. This north-seeking end of the magnet is its *north pole*. The opposite end is the *south pole*. A magnet behaves this way because the earth itself is a magnet. A magnet suspended like this is a compass.



Attraction and repulsion between poles

If the *S* pole of a second magnet is brought near the *N* pole of the suspended one, the *N* pole of the suspended magnet turns *toward* the *S* pole of the second magnet.



There is a strong force trying to pull the magnets together. In fact, the *N* pole of the suspended magnet would come together with the *S* pole of the other one if allowed to.

UNLIKE MAGNETIC POLES *ATTRACT* EACH OTHER.

Now if the *N* pole of a second magnet is brought near the *N* pole of the suspended one, the *N* pole of the suspended magnet turns *away* from the *N* pole of the second magnet.

There is a strong force repelling the two like poles.

LIKE MAGNETIC POLES *REPEL* EACH OTHER.

Why magnetism works

Why should a piece of steel or iron become a magnet, and be able to give evidence of such things as magnetic poles?

Certainly no outward change occurs. The piece of steel remains a piece of steel. The piece of iron remains a piece of iron.

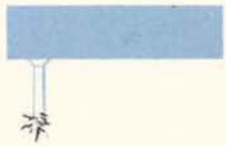
Yet something happens, and it can be explained this way:

Each of the molecules (or very small particles) that make up the steel or iron is a tiny permanent magnet. Normally, these tiny magnets are arranged helter-skelter like the members of a crew waiting around for the signal to "fall in." When the bar is magnetized, the molecules line up in order and all face the same way like a crew at attention. The molecules lined up in proper formation are able to do jobs they were not able to do previously.

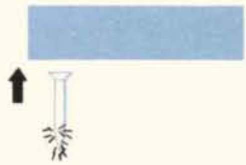
The tiny magnets line up so that their *N* poles all point toward one end of the bar. The *S* poles all point in the opposite direction. The *N* and *S* poles of the tiny magnets tend to neutralize each other in the middle of the bar. But at one end there is a set of unneutralized North poles and at the other, a set of unneutralized South poles. This explains the magnetic strength at the ends of the bar while the middle is comparatively weak.

Magnetic induction

A piece of iron or steel can be magnetized by stroking it with another magnet. But it can also become magnetized temporarily *without* being actually touched by a magnet.



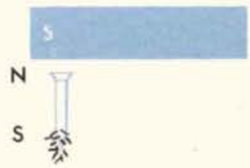
When a permanent magnet is placed *against* one end of a nail and the other end of the nail is brought into contact with iron filings, a mass of filings will cling to the nail. The nail itself has become a magnet.



When the nail is moved a little distance away from the permanent magnet, the filings still cling to it. The nail is still a magnet without being in contact with the permanent one. The nail acts as an extension of the magnet without touching it.

MAGNETISM PRODUCED *WITHOUT CONTACT* IS *INDUCED* MAGNETISM.

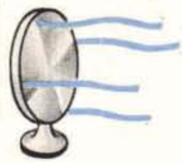
If the nail is moved farther away from the permanent magnet, the filings drop off. This shows that the nail was only a temporary magnet.



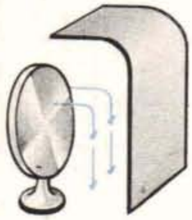
While the nail remains a magnet, it must have poles. To find the positions of the poles, the nail is brought up to the permanent magnet. The nail is attracted, and becomes attached to the magnet.

According to the rules of attraction and repulsion, unlike poles attract each other. If the pole of the permanent magnet that is near the nail is S, the induced pole attracted to the magnet is N. If the pole of the permanent magnet happens to be N, the induced pole attracted to it will be S.

Lines of Force



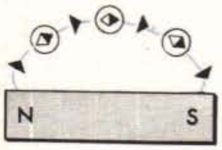
The lines of force around a magnet are invisible. But there are a lot of invisible things that can be proved to exist. For instance air and its flow are both invisible. But if an electric fan is turned on and strips of cloth are attached to the front frame, the waving of the strips show the flow of air that is created by the fan.



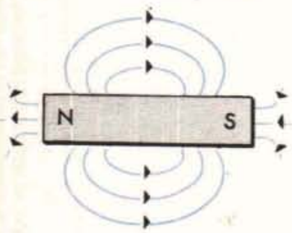
If the flow of air is deflected by a shield its direction could be represented by arrows.

In much the same way the invisible lines of force around a magnet can be shown.

In place of the cloth strips to show the flow of air from the fan, a compass is used to find the lines of force around a magnet.

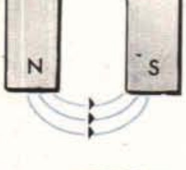


The compass is first placed near the *N* pole of the magnet and moved in the direction toward which the *N* end of the compass needle points. The compass marks out a path in a wide curve to the *S* pole of the magnet. This curve is the path of a line of force.

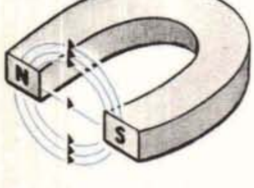


If this operation is carried out several times, the paths of the lines of force look like this, with the arrows showing the direction of travel.

Magnets of different shapes



Magnets are not all in the shape of a bar. The bar can be bent into a horseshoe shape. This is one of the most common shapes of a magnet.

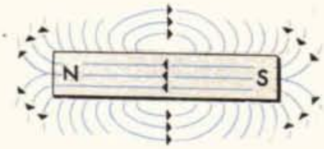


The lines of force around the poles of a horseshoe magnet seen from the bottom take this pattern.

The Magnetic Field

The many lines of force around a magnet form the *magnetic field.*

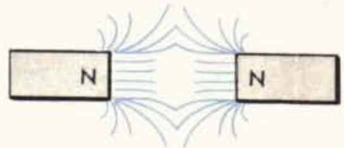
This field can be seen by covering the magnet with a piece of paper, sprinkling iron filings on the paper, and tapping it gently.



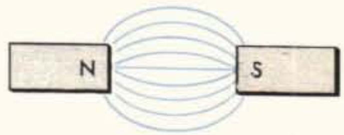
Each filing becomes a temporary magnet and sets itself in the direction of the line of force.

The filings lining up on the many lines of force show the pattern of the particular slice of the magnetic field through which the paper cuts.

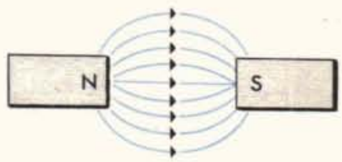
The pattern shows how the lines of force leave the magnet at the *N* pole, curve around and enter the *S* pole. In the magnet itself the lines pass straight from the *S* pole to the *N* pole.



If the *N* poles of two magnets are brought near each other, the lines of force repel each other. This is to be expected since *like* poles *repel* each other.



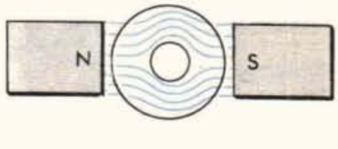
If the *N* and *S* poles of two magnets are brought near each other the lines of force pass from the *N* pole of the one magnet to the *S* pole of the other one. This shows again that *unlike* poles *attract* each other. The compass needle showed that magnetic lines of force travel from a *N* pole to a *S* pole.



Good and bad conductors

It is easier for magnetic lines of force to travel through some materials than through others.

A material that allows an easy passage of the magnetic lines of force is known as a *good magnetic conductor*. When such a material is brought near a magnet, as many lines of force as possible try to crowd their way through.



If an iron ring is placed between two unlike poles, the lines of force crowd through the iron of the ring instead of going around it. Very few of the lines travel across the hole in the ring, even though the distance through the hole is the shortest.

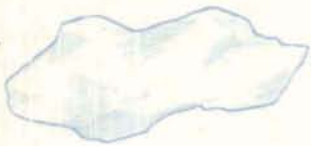
This shows that the lines of force find it easier to travel through iron than air.

The ease with which lines of force travel through a material shows the *permeability* of the material. The permeability of iron is great. The permeability of brass, glass, air, and other nonmagnetic materials is small.

Electric current is a flow

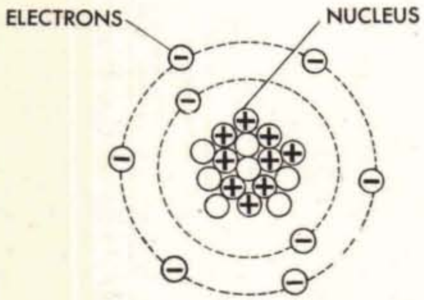
Electricity is a flow, but an invisible one. It is a flow of electrons.

An electron is a part of an atom.



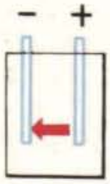
ALL MATERIAL THINGS ARE MADE OF ATOMS

All material things are made of atoms. The smallest thing visible under an ordinary microscope is made of almost countless numbers of atoms.

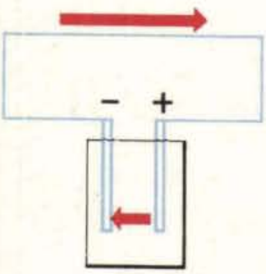


TYPICAL ATOM

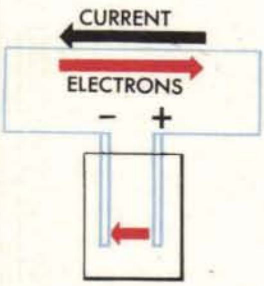
Each atom consists of electrons moving around a center. Each electron holds a negative charge of electricity. The center of the atom holds a positive charge. As in magnetism, unlikes attract, so electrons can be attracted by a stronger positive charge in another atom. This starts a flow of electrons from one atom to another.



In an electrical battery different metals are used for the poles. Chemical action is set up by the material in which the metal is placed. Then, the electrons collect on the negative pole.



If the poles are connected by a wire, the electrons that have collected on the negative pole flow *through the wire from the negative to the positive pole.* As chemical action is still taking place inside the battery, the electrons *in the battery cell* flow from the *positive to the negative pole.* In this way a complete circuit circle is made when an electric current is set up.



For many years it has been customary to consider the electric current as flowing from positive to negative. It is too late now to try to change this custom, so it is necessary to remember that the *current flow* is represented in diagrams as being *opposite* to the direction of the actual *electron flow.*

So much for pure theory—now for some definitions . . .

Measuring electricity

Energy

Electricity is a form of energy. Energy is the ability to perform work. Man has energy because he can lift things and carry burdens. Coal has energy because it can do work by producing heat. The powder charge in a gun has energy because it can do work by producing rapidly expanding gases upon explosion.

In performing work, electrical energy invariably takes other forms. When electricity is used to lift a load, electrical energy is transformed into *mechanical* energy. When electricity is used to heat furnaces, electrical energy is transformed into *heat* energy. When electricity is used to produce light, electrical energy is transformed into *light* energy.

Work

The most useful characteristic of electricity is its ability to perform *work*. Work may be defined as the overcoming of resistance. If a load of 50 lb. is lifted 1 ft., 50 ft. lbs. of work have been performed. Work is *measured* by multiplying the load displaced by the distance it is moved.

Power

Power is the rate at which work is done. A small electric motor with proper gearing might lift a given load 10 ft. in an hour. A larger motor that lifted the same load in 10 minutes would be six times as *powerful*.

Volts

The *pressure difference* that produces a flow of electricity is measured in *volts*. Comparing electricity with water, the voltage of electricity can be compared to the pounds of *pressure* per square foot exerted by a mass of water against the walls of a container.

Amperes

The rate of *flow* of electricity is measured in *amperes*. Just as the rate of flow of water is measured in so many gallons a minute, the rate of flow of electricity is measured in so many amperes.

Ohms

The *resistance* of any material to the passage of an electrical current is measured in *ohms*. Some materials are better conductors of electricity than others. Every material, however, offers *some* opposition to the flow of electricity. This opposition is known as *electrical resistance*.

Watts

The power of electricity is measured in *watts*. Power depends upon the rate of flow and the pressure. A watt, then, equals *one ampere* multiplied by *one volt*.

OHM'S LAW for direct current

NOTE:

When applying Ohm's Law to alternating current, resistance of the material is not the only resistance encountered. All electrical circuits resist any change in the flow of current. Because alternating current changes direction 120 times a second, this resistance called inductive resistance must be taken into consideration. When measuring alternating current, the inductive resistance is added to the resistance of the material and the two together are called the impedance.

Ohm's Law for alternating current is written

$$\text{Current} = \frac{\text{Voltage}}{\text{Impedance}}$$

When two measurements of an electrical circuit are known, it is easy to find the third measurement by Ohm's law. This law was named after George Simon Ohm who discovered it.

The law itself is expressed in this formula: $I = \frac{E}{R}$

I is the symbol for the current in amperes.

E is the electromotive force or difference in pressure between two points, expressed in volts.

R is the resistance of the circuit in ohms.

If there is a pressure difference of 6 volts and the circuit has a resistance of 3 ohms, $E = 6$, and $R = 3$. Then $I = 6/3$, or $I = 2$ amperes.

This law can be expressed in different ways. To find the resistance of a circuit, the formula can be turned around to read

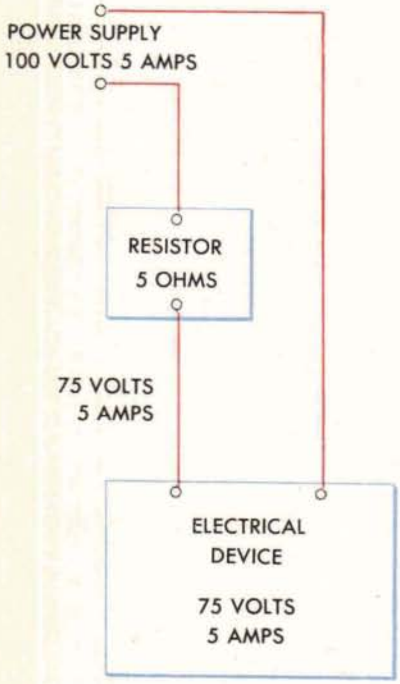
$$R = \frac{E}{I}$$

Using the same figures, with a pressure of 6 volts, and a flow of 2 amperes, $R = 6/2$, or $R = 3$ ohms.

To find the voltage drop when the current and the resistance are known, the formula is $E = IR$

Using the same figures again, where $I = 2$ and $R = 3$, $I \times R$ or $2 \times 3 = 6$ volts. So $E = 6$ volts.

By definition: Watts = amperes $\times$ volts $W = IE$
but since $E = IR$ W also $= I \times IR$ or $W = I^2R$



Controlling the current

Every electrical device is designed to operate within a certain voltage range. In order to use such a device in a circuit having a voltage higher than that for which the device was designed, it is necessary to reduce the voltage. A voltage dropping resistor can be used for this job.

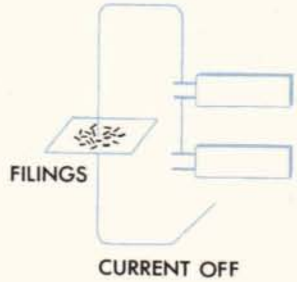
For example, an electrical device designed to operate at 75 volts with a current of 5 amperes, is to be operated on a 100 volt power supply. In this case the voltage applied to the device must be dropped 25 volts, and the current must be maintained at 5 amperes. Since voltage drop, E, equals current, I, times resistance, R, then $R = \frac{E}{I}$

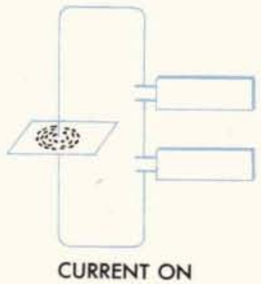
Substituting the actual values in the equation,

$$R = \frac{25 \text{ volts}}{5 \text{ amperes}} \quad \begin{matrix}\text{(desired drop in voltage)} \\ \text{(desired current flow)}\end{matrix} \quad R = 5 \text{ ohms}$$

Thus a 5 ohm resistor connected in the circuit will drop the voltage to 75, which is within the operating range of the device to be protected.

The directions of lines of force in a magnetic field





An electric current sets up a magnetic field.

The presence of this magnetic field is easy to prove. A wire is run vertically through a hole in the center of a horizontal cardboard sheet on which iron filings have been sprinkled. When the ends of this wire are connected to a battery, current will flow through the wire. If the cardboard sheet is now tapped gently, the iron filings will form concentric circles around the wire. These circles show the path of the lines of force in a magnetic field set up by the current flowing through the wire.

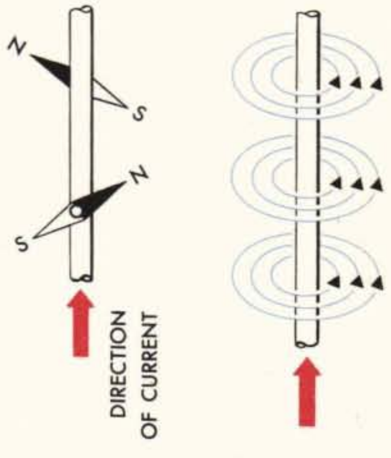
The *direction* of the lines of force in the magnetic field around the wire can be found by means of a compass.

If a wire with current running through it is placed on top of a compass, the north-seeking end of the needle turns at right angles to the direction of the current.

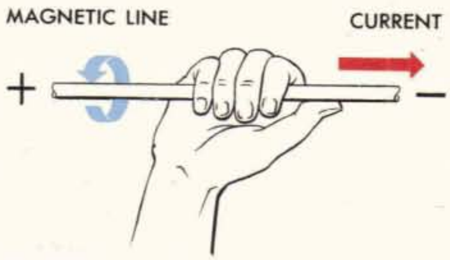
If the compass is put on top of the wire, the north-seeking end of the needle points in the opposite direction.

The north-seeking end of the compass needle indicates the direction of the lines of force in the magnetic field around the current flowing through the wire.

By placing the compass at various points around the wire, it is found that the lines of force make circles around the wire.

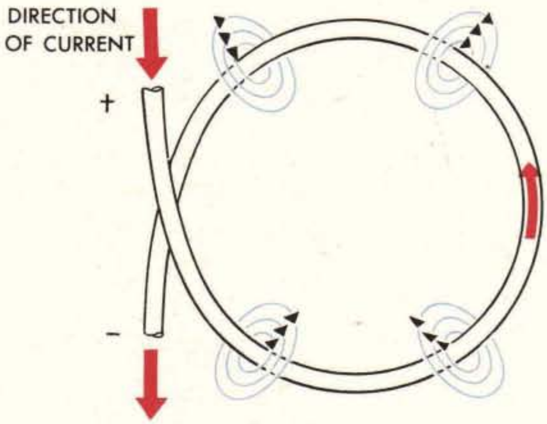


There is an easy method to find out the direction of lines of force in the magnetic field around a wire when the direction of the current is known. With the right thumb pointing along the wire in a direction from plus to minus, the fingers point in the direction of the field when the hand grasps the wire.

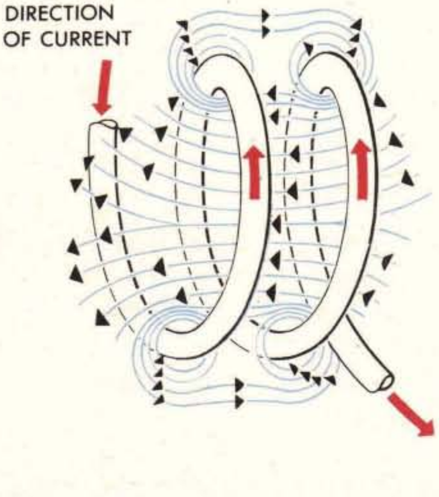


How a coil of wire produces

If a wire is made into a loop and a current of electricity runs through it, the rule of thumb still holds true. Grasping the wire with the right thumb pointing in the direction in which the current is flowing, the fingers point in the direction of the magnetic field.

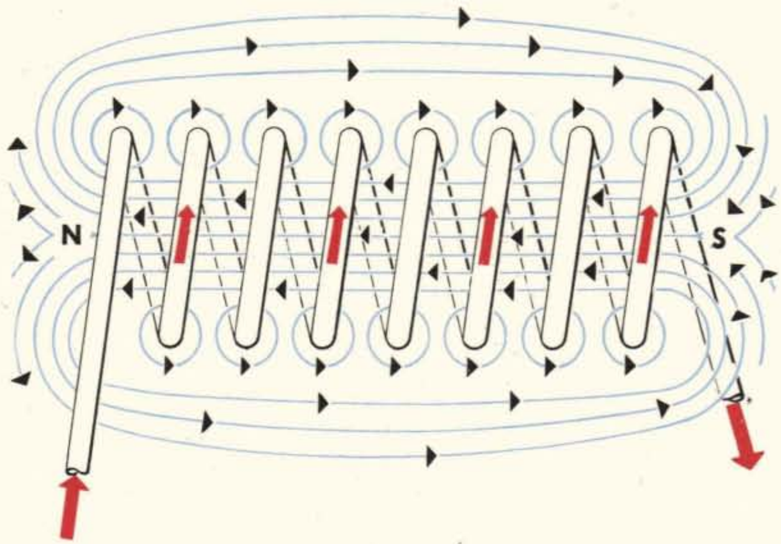


When the wire is coiled into two loops, most of the lines of force become big enough to include both loops. Their paths go through the loops in the same direction, circle around the outside of the two coils and come in at the opposite end.



a magnetic field

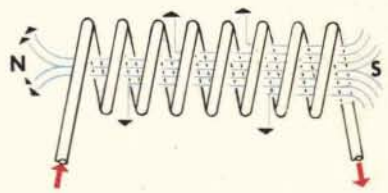
When the wire is looped a number of times, the lines of force make a pattern through all the loops. If the coil is grabbed by the right hand, with the fingers pointed in the direction of the current flow, the thumb points to the N pole of the coil's field.



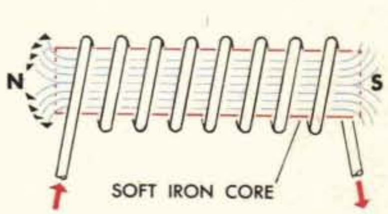
It's easy to see that this looks just like the magnetic field around a bar magnet. In fact, the coil has become a magnet.

A coil like this with air space through it is known as a *solenoid*.

Many of the lines of force, however, tend to stray between the loops of the solenoid, as indicated here. The magnetic force is thus scattered, or dissipated. To prevent such dissipation, a bar of soft iron is placed inside the coils of the solenoid.



The iron core affords an excellent path for the lines of force, which now become largely concentrated in the bar. This combination of coils and iron core produces an electromagnet.

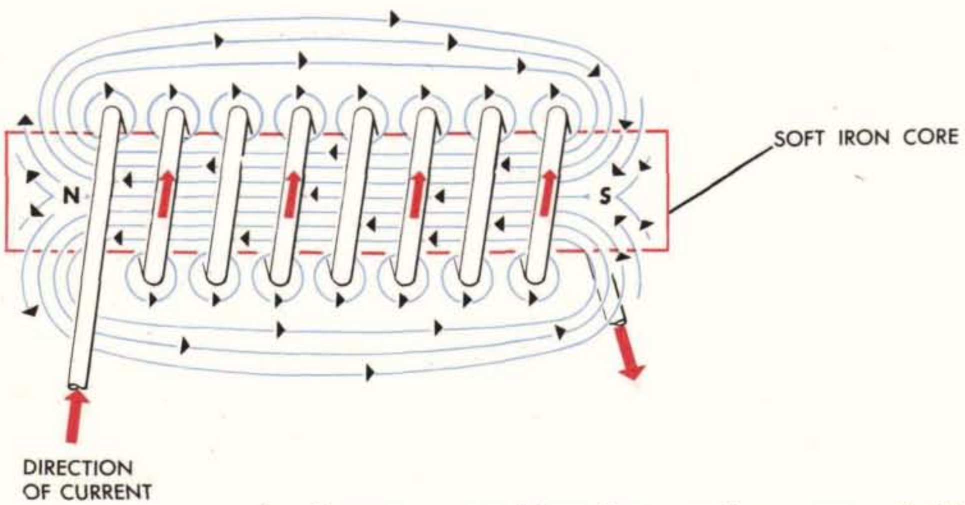


Strengthening the magnetic field

The strength of the magnetic field around an electromagnet can be increased either by increasing the number of loops in the wire or the flow of current through the wire.

Doubling the number of loops approximately doubles the strength of the field, each new loop adding its magnetic field to that already established. Doubling the amperage approximately doubles the strength of the field. Doubling the number of loops *and* doubling the amperage makes the field approximately four times as strong.

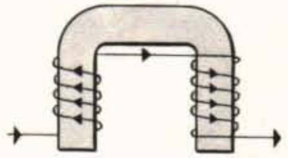
At a certain point, depending upon the size of the core of the electromagnet, a saturation point will be reached. Beyond this point, increasing the number of turns or increasing the amperage will not increase the strength of the field.



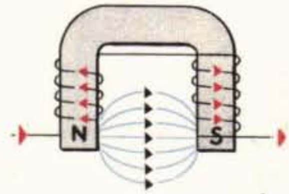
An electromagnet with an iron core has a magnetic field only while current is running through its coils. A reversal of the current reverses the poles.

An electromagnet need not be straight

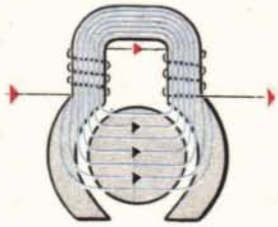
The soft iron core of an electromagnet can be bent into the shape of a horseshoe. A great many turns of wire are used in actual practice. For the sake of showing the direction of the current, only a few turns of wire are shown in the illustration.



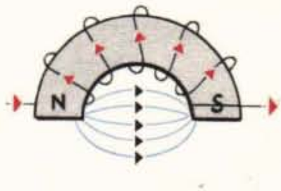
Following the laws of magnetism the magnetic field has its greatest strength at the poles. The field looks like this.



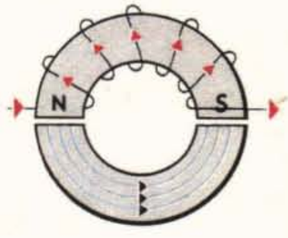
The arms of the iron core are often bulged. An iron disk or ring is put between them. Then the lines of force go through the disk or ring with very little leakage into the air between the poles.



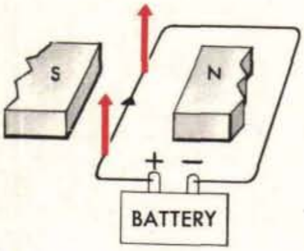
The electromagnet can also be bent into a semi-circle. The magnetic field has the same shape as in the horseshoe.



Then if another semi-circle of iron is fitted onto the magnet, practically all the lines of force go through the second semi-circle. Almost none of the lines of force escape into the air. This is one of the strongest kinds of electromagnets.

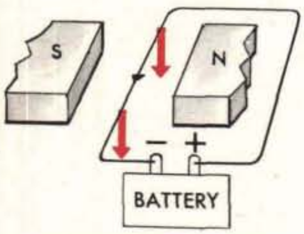


How magnetism makes

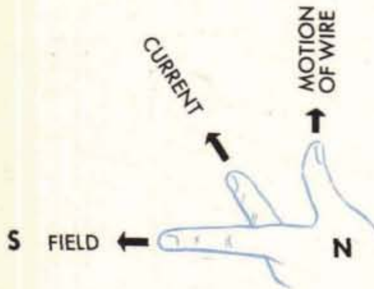


Place a length of wire between the poles of either a natural or an electromagnet. Attach the ends to the terminals of a battery with a switch in the line.

As soon as the current is turned on, the wire is kicked upward as shown by the red arrow.

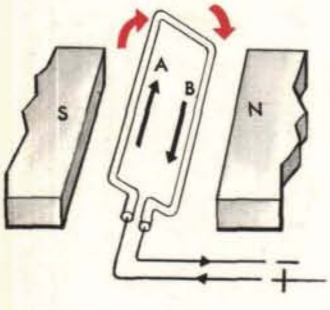


Reverse the connections to the battery. The wire between the magnetic poles is kicked downward.



Here is a rule for finding out the direction of the current as well as the direction in which the wire will be kicked:

Place the thumb and first two fingers of the *left* hand in the position shown. The first finger must be pointed from the *N* pole of the magnet to the *S* pole. Then the second finger shows the direction in which the current is flowing. The thumb points in the direction that the wire will move.

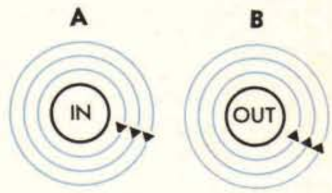


The direction of a current in one side of a loop of wire is opposite to the direction on the other side. When the loop is placed in a magnetic field, one side *A* kicks upward. The other side *B* kicks downward. If one side goes up and the other side goes down, the loop turns around, or rotates.

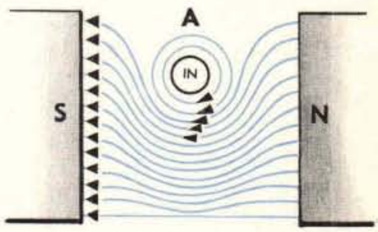
a motor turn

Here's why one side of the loop goes up and the other side goes down.

A magnetic field is produced around a wire when an electric current flows through it. Looking at the "IN" and "OUT" ends of the wire that forms the loop, the magnetic lines of force look like this.

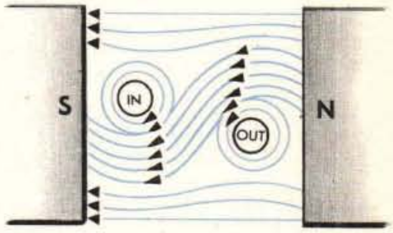


When the loop is put between the poles of a magnet, the magnetic field around the wire combines with the field between the poles of the magnet. Looking at the end of the wire where the current is flowing in, it is seen that more lines of force gather under the wire than above it.



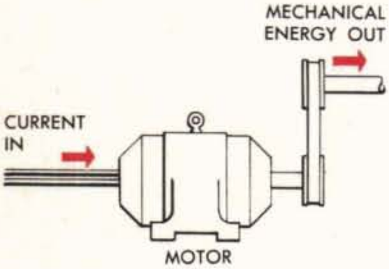
It is the natural tendency of the lines of force to take the shortest path between the poles of the magnet. It can be compared with the tendency of a rubber band to straighten out when stretched. Anything on top of the rubber band will be pushed up. In the same way the wire is pushed up by the lines of force because there are more lines of force under the wire than over it. This is called the *motor effect*.

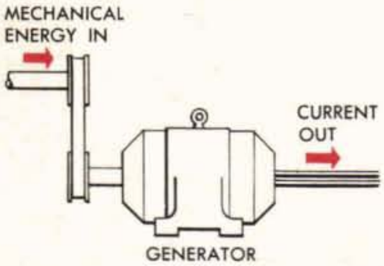
When the lines of force around the "OUT" side of the loop combine with the magnetic field between the poles of the magnet, there is a concentration of the field above the wire. This tends to push the "OUT" side of the wire down.



So the loop rotates as one side is pushed up and the opposite side is pushed down. A shaft attached to the loop would turn with it, and could be used to perform many jobs. Then the whole assembly is the basis of a motor.

Contrast between electric motors and generators



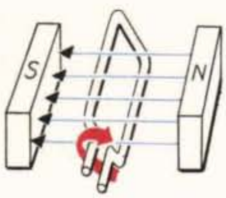


It has been shown that when a wire loop is placed in a magnetic field and an electric current is passed through the loop, the loop rotates. Rotation of such a loop can be used to supply mechanical energy. For instance, in an electric motor, many loops or "coils" are wound around the rotor of the motor, and the rotor is placed in the magnetic field produced by poles of an electromagnet. When current is supplied to these coils the rotor turns. A pulley or gear is attached to the rotor and, by means of belting or gearing, other mechanisms are driven. An input of electrical energy to the motor, therefore, results in an output of mechanical energy which can be used to drive various types of mechanical apparatus.

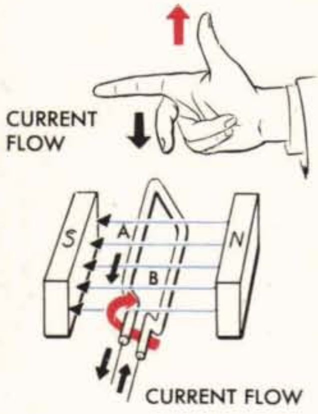
The opposite operation can also be performed. The coils of a rotor can be turned by mechanical means, and current can be obtained from the coils. In this case, an input of mechanical energy results in an output of electrical energy. The machine which converts mechanical to electrical energy is a *generator.*

It can be said that in a *motor,* electricity produces magnetism, and in a *generator,* magnetism produces electricity.

How magnetism generates electricity



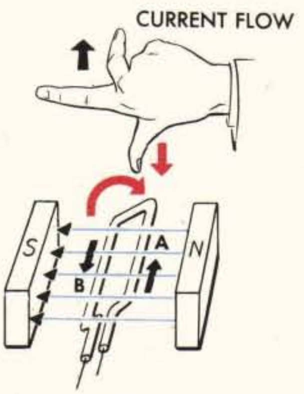
It is easy to construct a simple generator by putting a loop of wire between the poles of a magnet. As the loop is turned, it cuts the lines of force between the poles. This induces an electric current in the loop. Then current flows through the wire in a direction that can be determined by this *right* hand rule:



The first finger points from the *N* to the *S* pole of the magnet. The thumb, at right angles to the first finger, points in the direction of the motion of the rising wire *A.* Then the second finger, held at right angles to the wrist, points in the direction of the current in this wire.

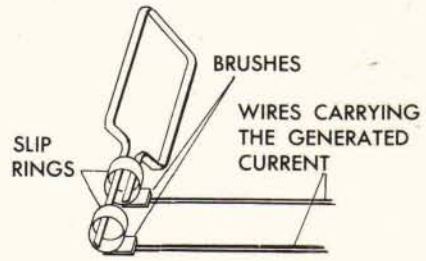
Alternating Current

Alternating current is a flow of electricity that alternates from one direction to the other. It can be generated in a magnet and wire loop set-up like this:



It has been seen that as wire *A* moves upward through the magnetic field, cutting the lines of force, the right-hand rule shows the direction of current flow.

As the loop continues to rotate, wire *A* reaches a maximum point in its upward travel and then starts moving in a downward direction. Since wire *A* is now cutting the lines of force by traveling in the opposite direction, it is necessary to turn the right hand upside down to find the direction of current flow. It will be seen that when the direction of travel of wire *A* reverses, the direction of the current reverses. This occurs with each complete half turn of the loop.

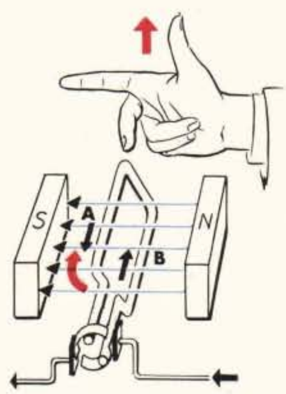


The loop of wire turning constantly in the magnetic field now generates *alternating current*. Alternating current is usually abbreviated A.C.

With this set-up, it would not be possible to turn the loop many times without the lead wires which receive current from the loop becoming entangled. The ends of the loop, therefore, are attached to slip rings which turn with the loop. Pieces of spring metal, known as brushes, press against the rings and carry the current flow to the wires.

Direct Current

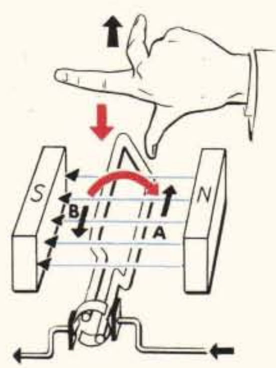
Direct current is a flow of electricity that remains constantly in one direction.



To make a generator supply direct current, a split ring is put on the axle that turns the loop. This split ring is known as a commutator.

When wire *A* is moving up, the current as shown by the right-hand rule, is coming off the loop through one half of the commutator and the upper brush.

When *A* has passed its maximum point of upward travel and is descending, the current in the loop is reversed. But the *A* part of the loop is now connected with the lower brush. The current, therefore, goes out in the same direction as before.



The upper brush is always connected to the part of the loop that is going up.

The lower brush is always connected to the part of the loop that is going down.

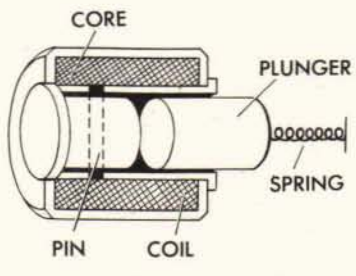
This being so, the direction of the current remains the same all the time in the outside lines.

SIGNAL, LOCK and CLUTCH

SOLENOID SIGNALS

Signals are a convenient device for saying YES or NO. An example of their use is in the Computer Mark 1, where they are turned on to say "YES, rate control corrections are being made at the director," or left off to say "No corrections are being made."

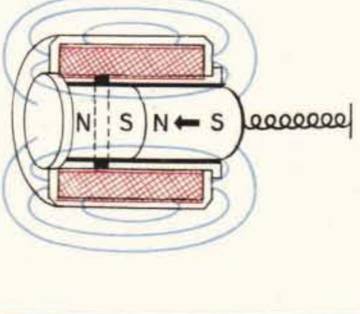
Reviewing Solenoid Action



A simple solenoid is a coil of wire.

The solenoid used in the solenoid signal contains a steel core and a steel plunger.

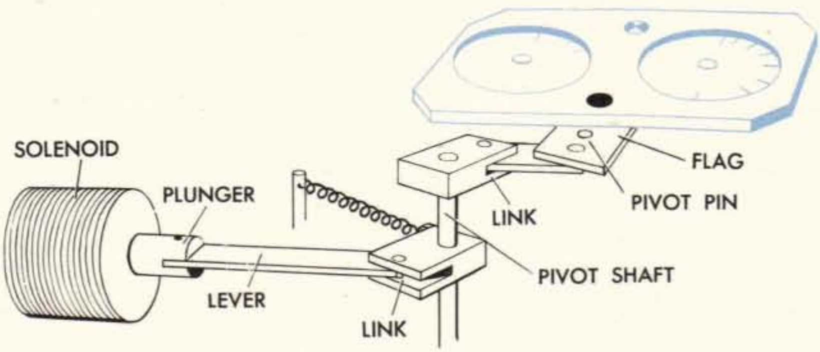
When the current is off, the plunger is held away from the core by a spring.



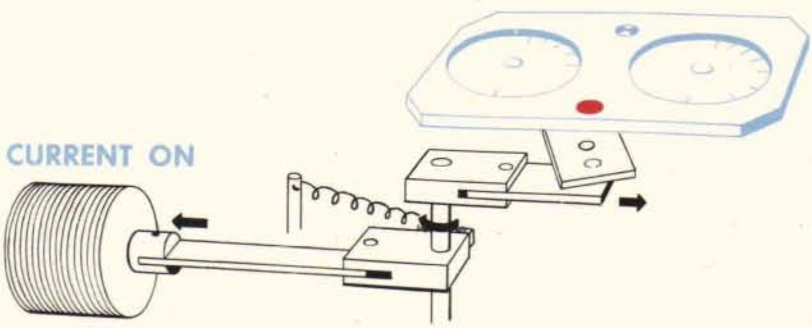
When the coil is energized, a magnetic field is formed inside it. The core and plunger become magnets, and their opposite poles are attracted to each other. Since the core is pinned in position, the magnetic attraction draws the plunger into the coil.

How the signal works

In the solenoid signal, the plunger is connected through levers and links to the signal flag.



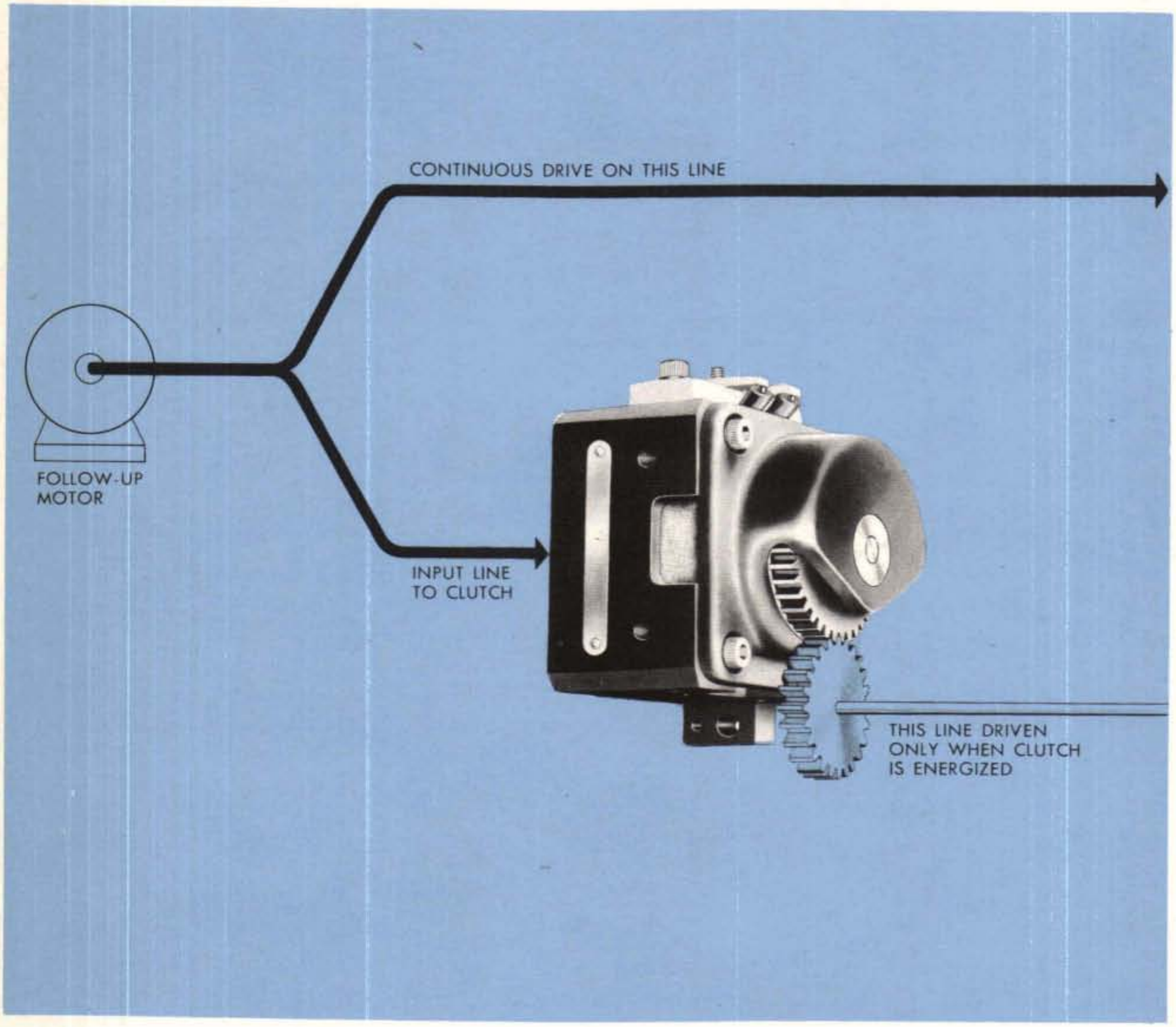
When the solenoid is not energized, the spring holds the black part of the signal flag under the hole in the dial mask.



When the rate control key in the director is pressed the solenoid is energized.

The plunger is pulled into the solenoid coil. This turns the pivot shaft and swings the red part of the signal flag into view under the hole in the dial mask.

The Solenoid CLUTCH



THIS IS HOW THE CLUTCH IS SHOWN ON SCHEMATICS

A CLUTCH connects and disconnects a line of gearing.

When this clutch is engaged the motor drives the output line from the clutch. When the clutch is open, the output line from the clutch will not be turned even though the motor continues to drive the input.

The clutch jaws are held open by a spring until they are engaged by the same kind of solenoid action which operates the solenoid signal just described.

An inside view of the clutch

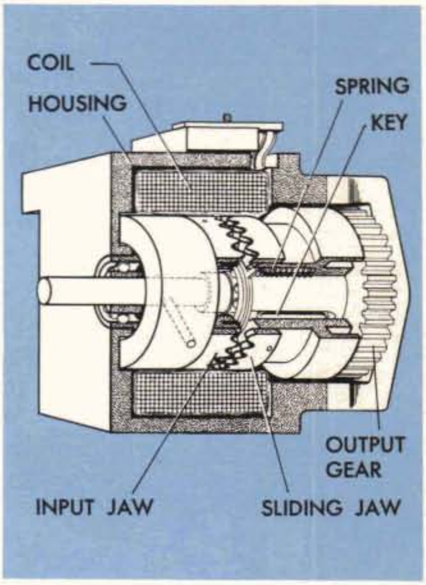
The solenoid clutch consists of two cylindrical jaws set inside a solenoid coil.

The *input* shaft rotates one jaw.

The other jaw is mounted on the hub of the *output* gear. This is the *sliding jaw.*

The sliding jaw is free to slide on keys which are set between the jaw and the hub of the gear. While the keys allow the jaw to slide back and forth on the output gear hub, they prevent the jaw from turning on the hub. The hub and jaw must turn together.

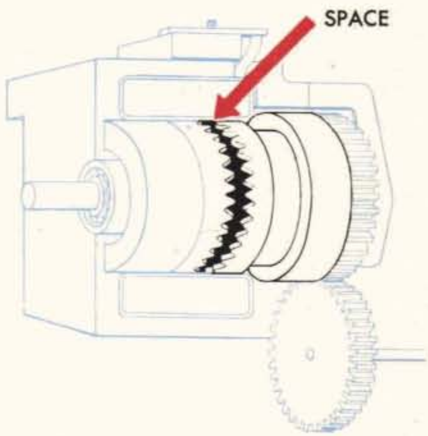
Three springs hold the sliding jaw out of engagement with the input jaw when the magnetic field is dead.



How the clutch works

When the current is OFF

There is no magnetic action. The springs hold the sliding jaw out of engagement with the input jaw. The input shaft and jaw may turn, but they have no effect on the output gear—*the two jaws are not connected.*

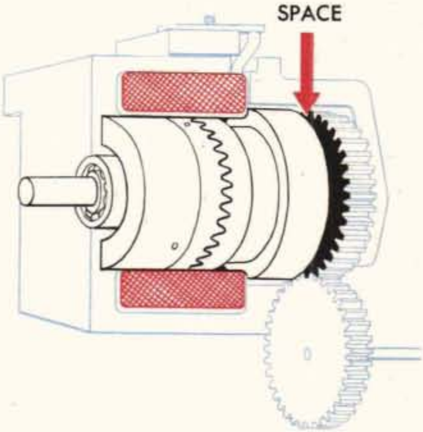


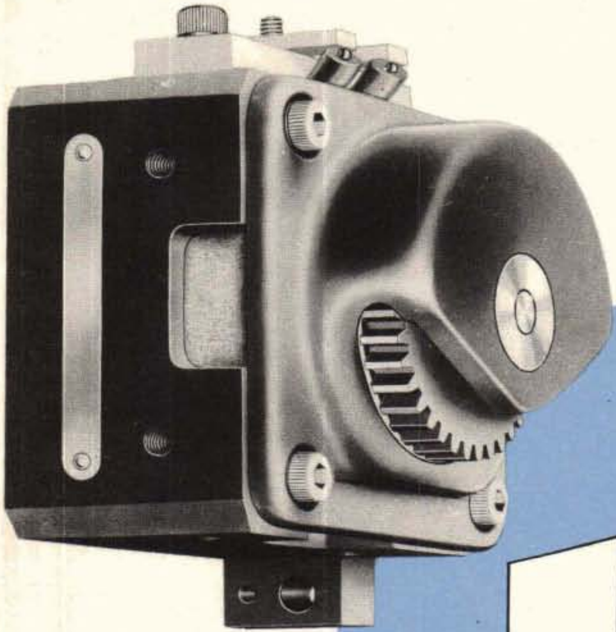
When the current is ON

Both metal jaws become magnetized.

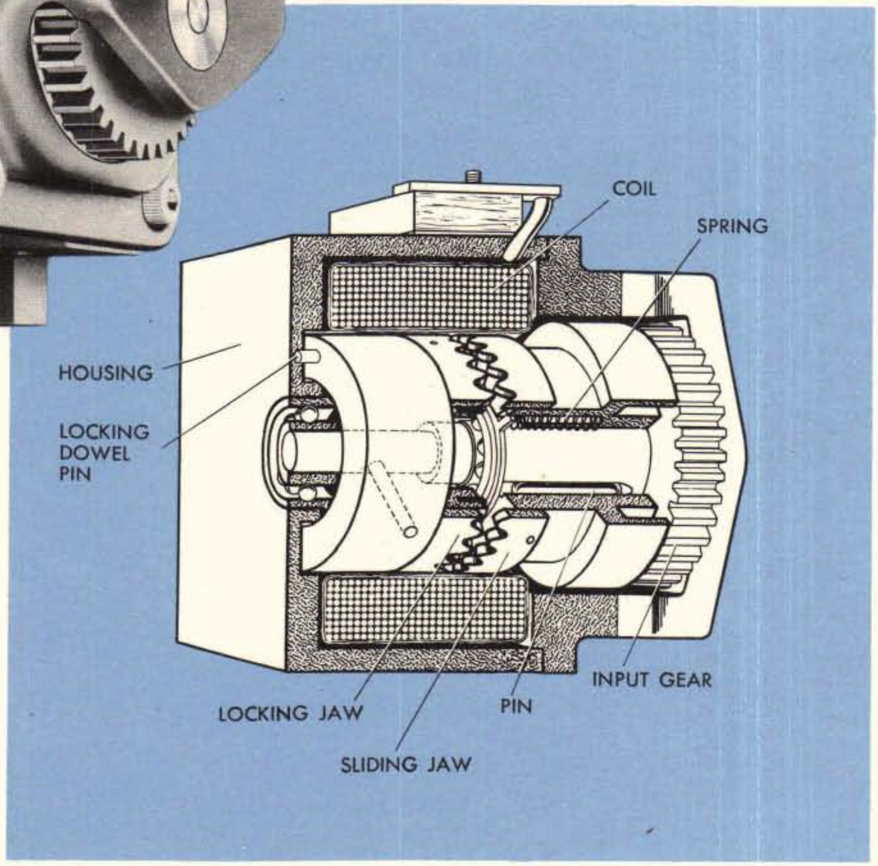
The opposite poles of the magnets attract each other. The sliding jaw is pulled into mesh with the input jaw and the two jaws turn together.

In this position, the output shaft will be driven by the input shaft.





The LOCK

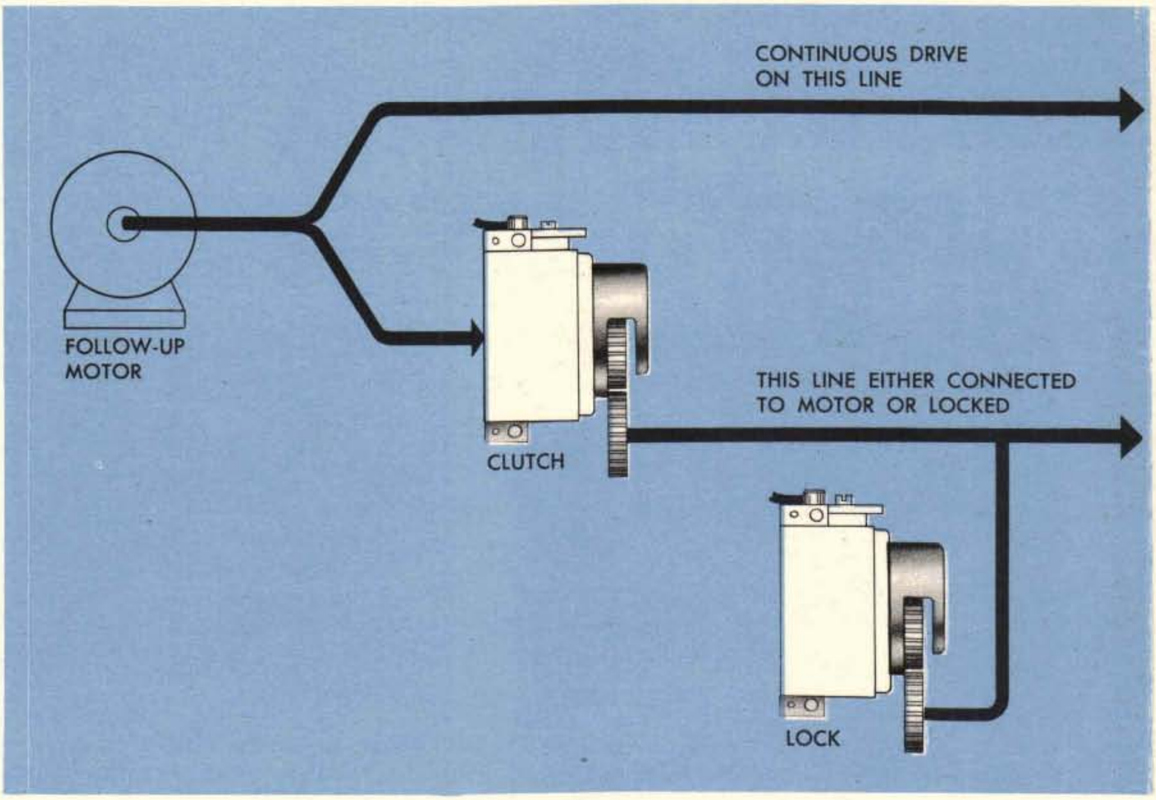


A LOCK is used to prevent a line of gearing from turning.

The solenoid lock works just like the solenoid clutch except that one of the jaws is locked to the housing by a dowel pin. The other jaw is attached to a gear, and is free to turn as long as the lock is de-energized. The gear is the *input* gear to the lock.

ON SCHEMATICS THE LOCK IS SHOWN THIS WAY

When the current is ON the two jaws are engaged. The whole shaft line connected to the input gear is then locked to the housing through the locking jaw.



How the clutch and lock work together

The clutch and lock are often used together. When a computer is switched from one type of operation to another, certain lines must be connected or disconnected, and the disconnected lines must be held in position while they are not being used.

Here is an example in which both a clutch and a lock are used on the same line. When the clutch is energized, the lock is de-energized and the motor drives the line.

When the clutch is de-energized, the lock is energized and the line is held stationary.

ELECTRICAL SWITCHES

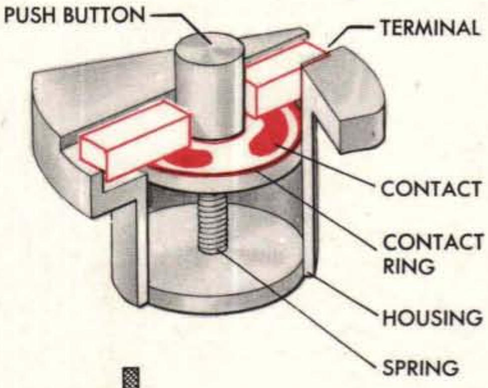
A switch is a mechanism which can make or break an electrical circuit.

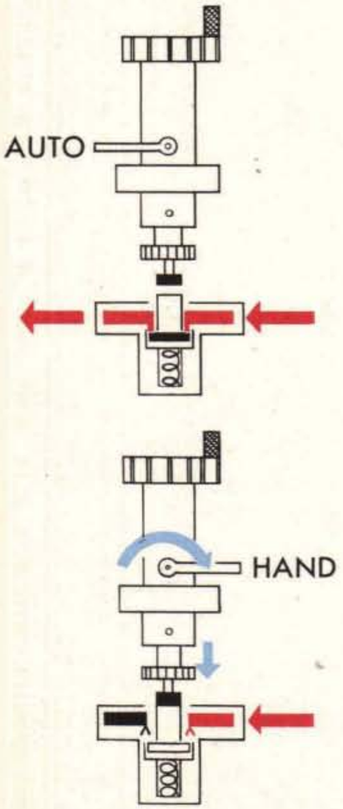
It must operate fast in order to prevent excessive arcing between terminals and contact points. Frequent arcing burns the metal and will soon cause either a poor contact or a complete break in the electrical circuit.

Switches have two main uses:

1. They turn the electrical power off and on.
2. They switch electrical power from one circuit to another.

The PUSH BUTTON SWITCH





The push button switch is a two-position switch for making and breaking an electric circuit.

It can only be used to turn power OFF or ON.

This switch consists of a housing containing a pair of specially shaped contacts, and a push button with a ring of contact material above its base.

The push button contact ring is held against the contacts by a spring.

The push button switch is usually operated by a two-position hand crank.

The two positions of the hand crank are usually for "automatic" and "hand" control.

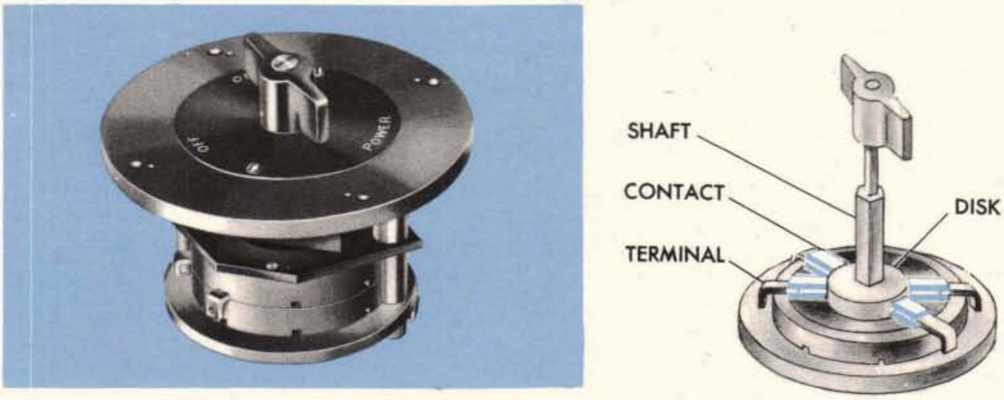
When the hand crank is set at AUTOMATIC, the switch-bolt is in its raised position.

The spring in the push button switch holds the contact ring against the contacts. The electric circuit is closed and the shaft line is positioned electrically.

When the hand crank is at HAND, the switch-bolt holds the contact ring down away from the contacts.

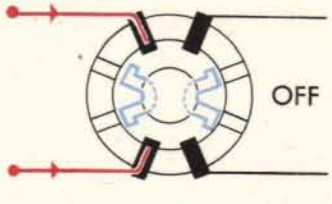
The electrical circuit is broken and the shaft line can be positioned by the hand crank.

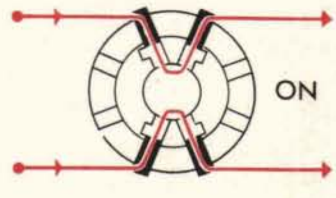
The ROTARY SWITCH



A rotary switch can be used either as an ON and OFF switch or as a multiple switch, to change current from one circuit to another.

The ROTARY SWITCH used as an **ON and OFF switch.**





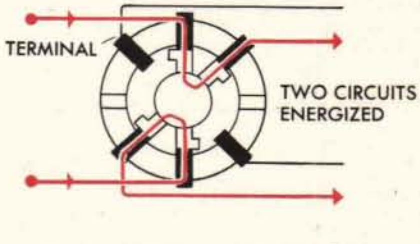
The shaft of the rotary switch is controlled by a spring and detent arrangement which allows the shaft to make only a quarter turn at a time. As the switch is turned the spring is tightened and then suddenly released, so that the shaft snaps around and makes its quarter turn very fast.

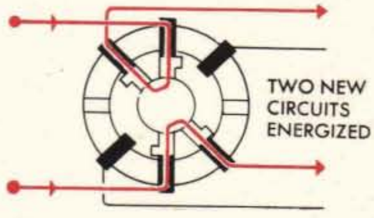
Around the base of the switch are two pairs of terminals. The shaft going through the center of the switch carries a pair of double contacts mounted in a disk.

When the switch is OFF the contacts are away from the terminals and the circuit is broken.

When the switch is ON, the shaft turns a quarter turn bringing the contacts against the terminals. The circuit is made.

The ROTARY SWITCH used as a **MULTIPLE switch.**



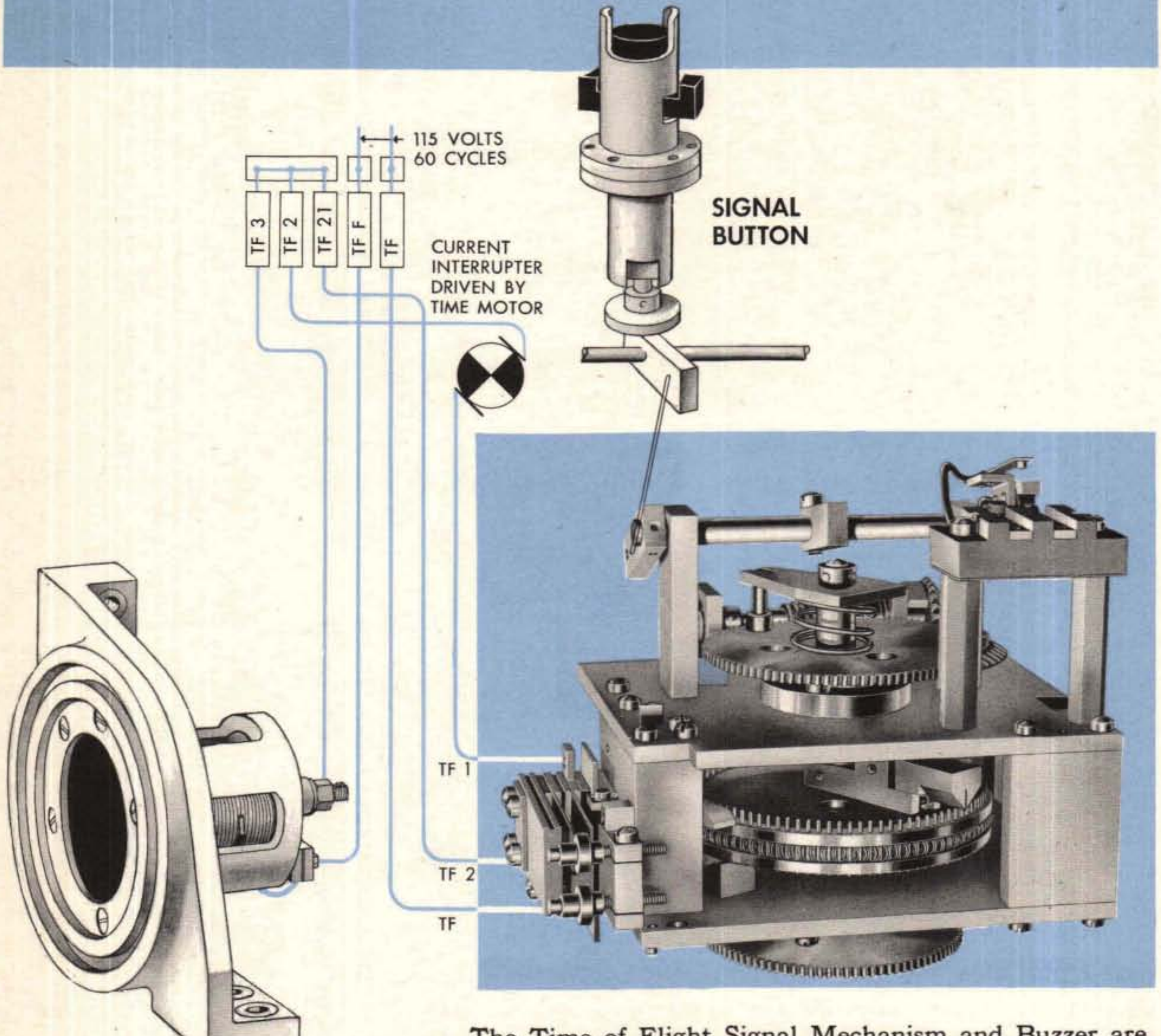


When the rotary switch is used to change current from one circuit to another, it has a different detent arrangement so that the shafts and contacts only move 1/8 of a revolution when the switch is turned.

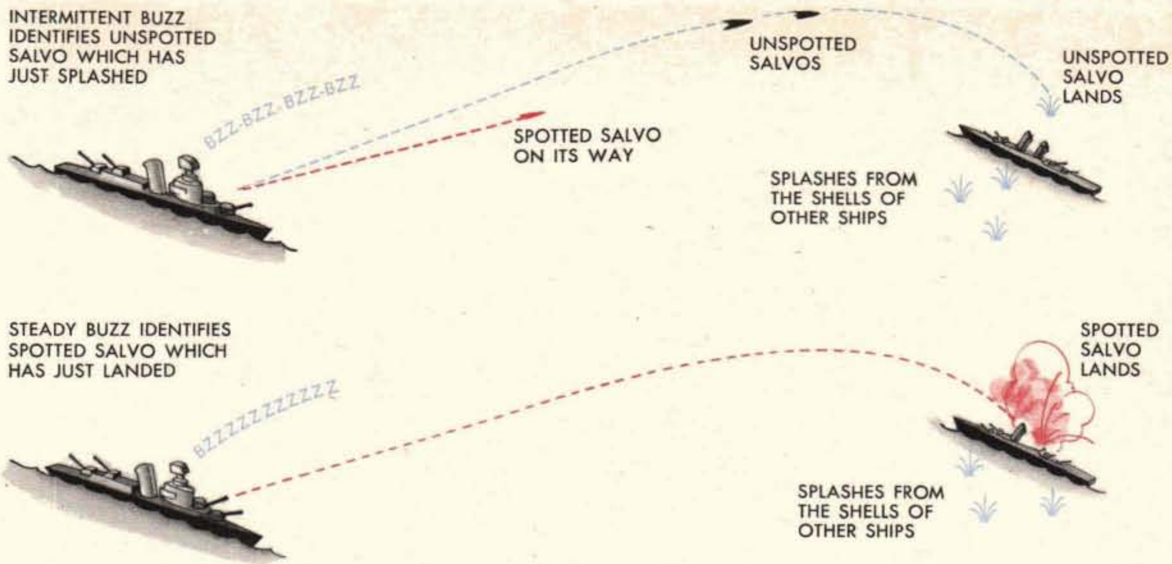
By making 1/8 of a turn, the contacts change the flow of current from one circuit to another.

These two positions of the contact points represent two switch positions, such as "Automatic" and "Semi-automatic." When other positions are needed, the switch can be built up in layers of contact points and terminals—to accommodate the additional positions.

TIME OF FLIGHT
signal mechanism and buzzer



The Time of Flight Signal Mechanism and Buzzer are used with several of the main battery Range Keepers. They enable an observer to identify any particular salvo. The signal mechanism sounds a buzzer at the observer's station which tells the observer when the salvo in which he is interested is about to land.



There are at least two reasons why observers are interested in particular salvos:

1 Shells from other ships may be landing around the target. The observer must single out the splashes of one of the salvos from his own ship in order to find out how close to the target his shells are landing.

2 From observation of shell splashes the observer estimates the deflection and range spot corrections which he will need to put the shells on the target. The important thing in spot correcting is to keep track of the particular salvo which has been spot-corrected in order to observe the effect of the spots.

Unless the observer knows which salvo has been spot-corrected, this may happen:

The observer calls for a set of spots.

Meanwhile several salvos on which the spots have not taken effect have been fired and are in the air.

These unspotted salvos miss and the observer, seeing their splashes, thinks his first spots were not large enough and overspots.

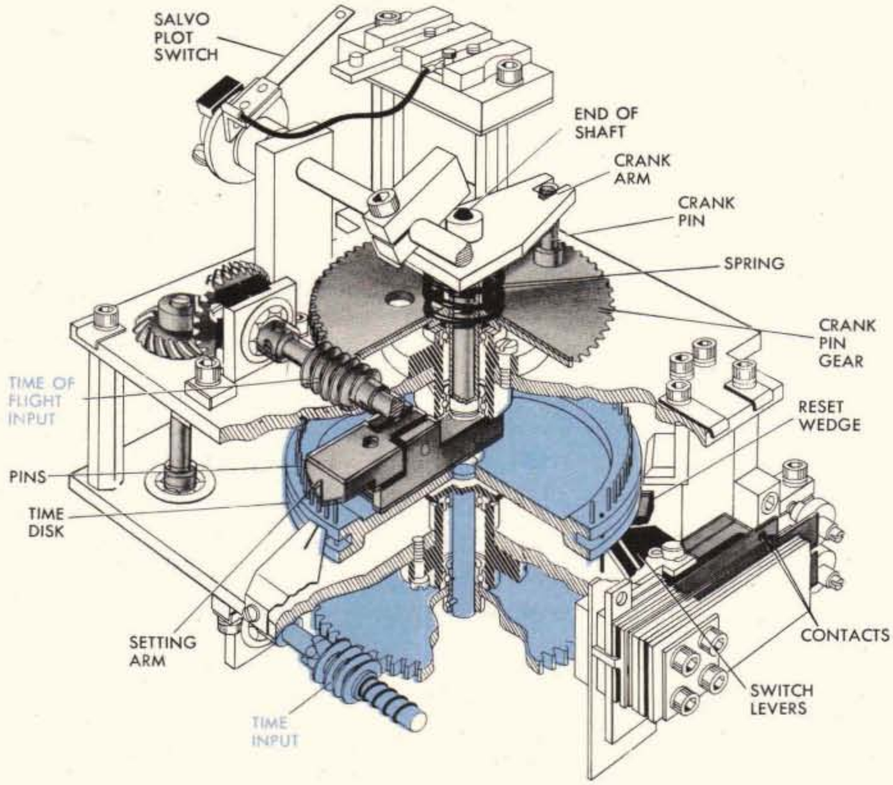
With a time of flight mechanism, it is easy to keep track of any particular salvo, because the same value of time of flight that goes into the gun order is used to time the buzzer.

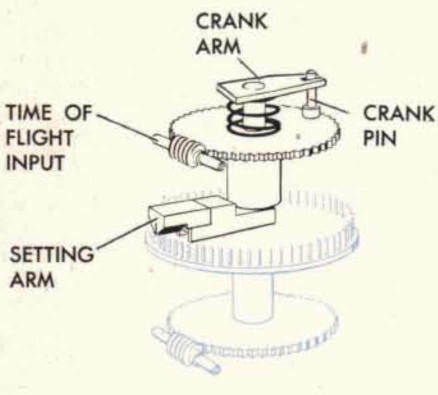
When the salvo is fired, the *Time of Flight Button* is pressed to set the signal mechanism. The signal mechanism sounds the buzzer just before the shells land.

An interrupted buzz identifies a salvo which has *not* been corrected by spots.

A steady buzz sounds for a spotted salvo.

Here is the TIME of FLIGHT MECHANISM





TIME OF FLIGHT and TIME feed into the signal mechanism continually, whether the signal mechanism is being used to sound the buzzer or not.

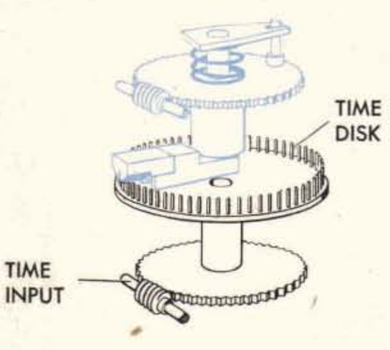
The TIME OF FLIGHT input

Time of Flight from the *Tf* ballistic cam comes in continuously through a worm that turns the gear on which the crank pin is mounted.

The crank pin extends up through a notch in the crank arm and turns the crank arm.

The setting arm is mounted on the same shaft as the crank, so that when the crank is turned the setting arm turns with it.

In this way TIME OF FLIGHT POSITIONS THE SETTING ARM.



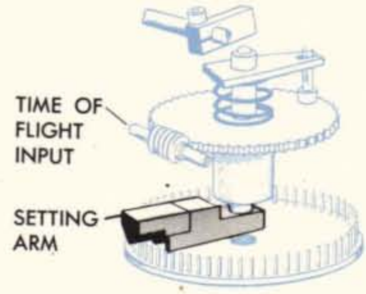
The TIME input

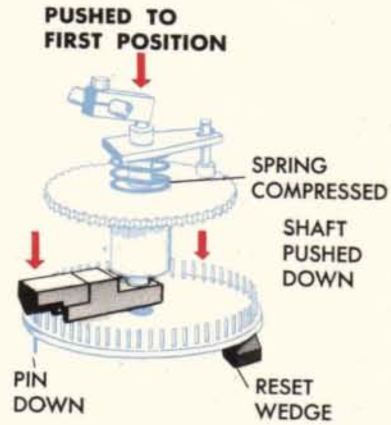
Time from the time motor comes in through a worm which rotates a gear on the lower shaft. This same shaft carries the time disk around. The time disk rotates all the time at a constant speed.

This disk holds pins closely spaced at equal intervals around its rim.

These two inputs keep the signal mechanism in constant readiness to receive a setting from the TIME OF FLIGHT SIGNAL BUTTON.

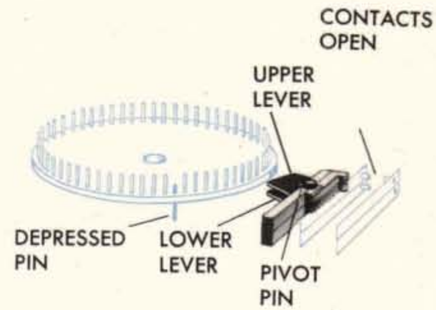
and here is how it works



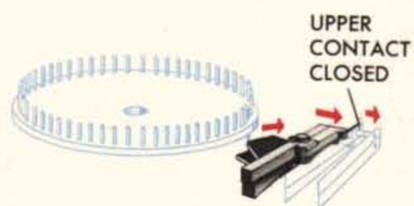


The *Time of Flight* signal button moves the setting arm down.

A spring returns the setting arm.

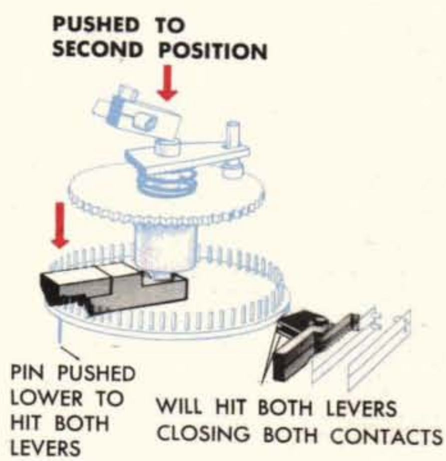


When the button is pressed, the arm pushes down the nearest pin on the moving time disk.



As the time disk rotates, the pin which was pushed down is carried around until it hits the upper lever, closing the upper contact to the switch.

The switch closes the circuit to one or more Time of Flight buzzers and an *interrupted buzz* results.

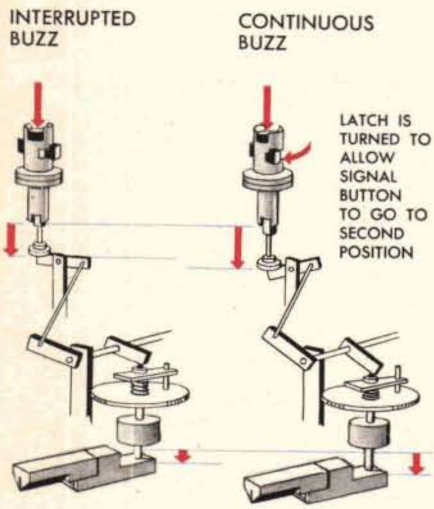


However, when it is necessary to distinguish a salvo which has been spot corrected, the button is pushed further, making the arm push one of the pins *lower* than in normal operation.

The pin in the *lower* position engages *both* levers, which close both contacts to the switch. A *continuous buzz* results.

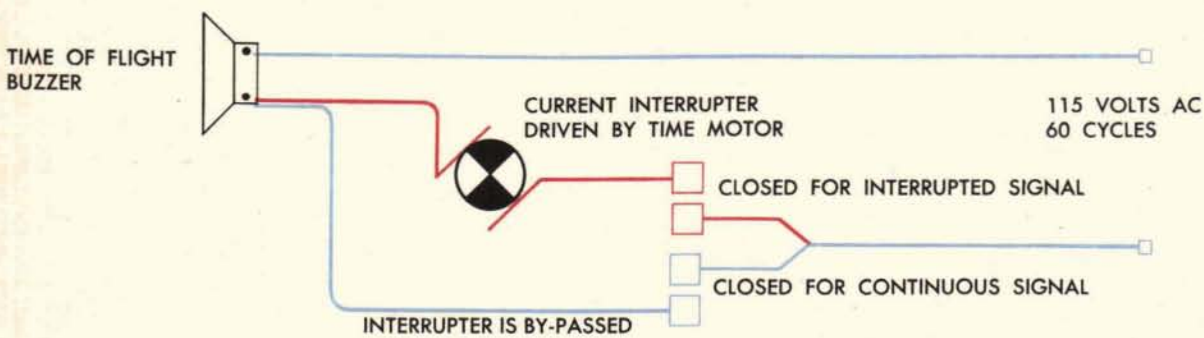
After passing the switch levers the pin is carried over the reset wedge which pushes it up to its original position.

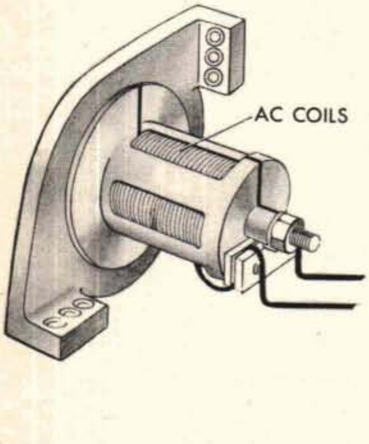
The two kinds of buzzes: interrupted continuous



The interrupted buzz is used to identify salvos which have not been spot-corrected. It is produced by sending the current through an interrupter which alternately opens and closes the circuit. The upper contacts make the connection to the interrupter. When the lower contacts are also closed, the current bypasses the interrupter to produce a steady buzz.

The Time of Flight signal button has two positions. The first position lowers one of the pins enough to trip the upper contacts, and send the current through the interrupter. The second position pushes the pins low enough to close *both* sets of contacts and bypass the current around the interrupter.





The Time of Flight BUZZER

The buzzer works through a solenoid. The solenoid is connected across a 115-volt 60-cycle *AC* circuit. The alternating current causes a plunger to vibrate back and forth.

The plunger vibrates the diaphragm and it is this vibration which produces the buzzing sound.

The TIME of FLIGHT mechanism in ACTION

If the Time of Flight signal button is pressed when the salvo is fired, the buzzer will sound just before the splashes are visible.

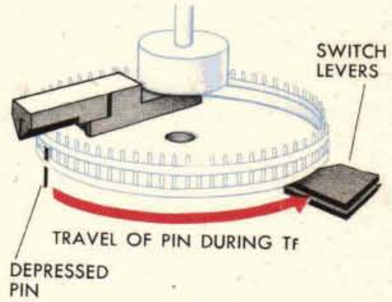
The length of time which elapses between the pushing of the button and the sounding of the buzzer depends on the *distance* the pin has to travel from the time it is depressed until it touches the lever.

The setting arm is positioned by Time of Flight and it depresses the pin at the beginning of Time of Flight.

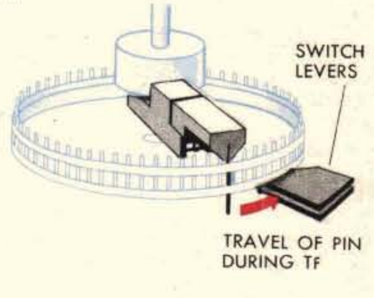
The pin is carried by the time disk, which is always turning at a constant speed independent of the setting arm.

So the distance the pin has to travel from the time it is depressed until it touches the lever corresponds to Time of Flight, *Tf*.

Here Time of Flight is quite long ... The depressed pin must travel quite a distance to reach the lever which closes the switch and causes the buzzer to sound.

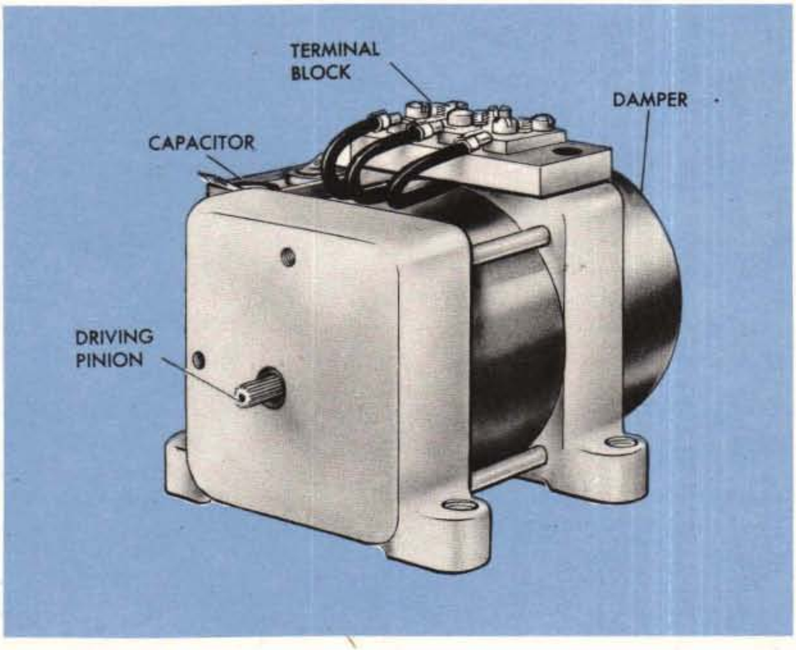


Here Time of Flight is short ... Notice that the depressed pin must travel only a short distance to reach the lever which closes the switch.



It is easy to see how the angular position of the arm which depresses the pin controls the distance the pin must travel to the switch lever. This angular position is set in by Time of Flight. Therefore, the distance traveled is proportional to the Time of Flight, except for a slight advance to allow the signal to precede the splashes.

SERVO MOTORS



The various mechanisms in a Computer, such as component solvers, vector solvers, and multipliers do not have outputs powerful enough to position heavily loaded shafts. Outputs from such mechanisms often merely control the action of electric servo motors, and these motors do the actual positioning.

The servo motor is an induction type motor. That is, the rotor is not connected directly to the power supply, but has current "induced" in it by the action of a magnetic field. This field is produced by the stator coils when 115-volt *AC* current is supplied to them.

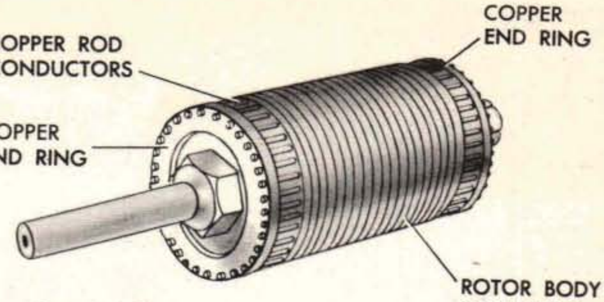
The induced current in the rotor creates its own magnetic field, and as this field strives to "line up" with the rotating stator field, the rotor is made to revolve. (See page 342.)

The servo motor consists of four major parts: Two end frames
A Rotor
A Stator

The rotor shaft runs in ball bearings mounted in holes in the end frames.

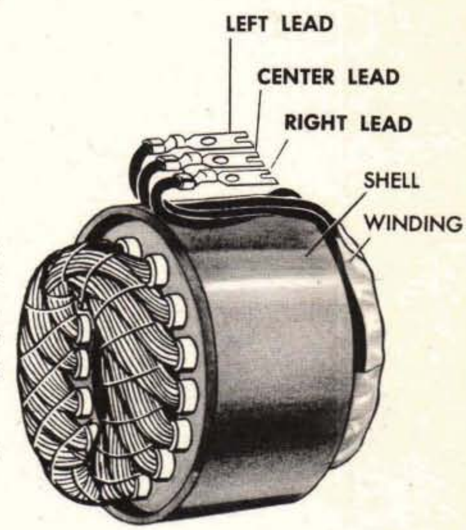
The ends of the stator shell fit into the end frames, and four bolts hold the assembly together.

One end of the rotor shaft can either be cut to form a pinion, or a pinion can be mounted on it. The opposite end of the shaft often carries a "damper."



Rotor

The rotor is of the squirrel cage type, consisting of a number of iron disks. Each disk is pierced with holes around its circumference, and through these run copper rod conductors. The ends of these conductors are joined to copper end rings. Neither brushes nor slip rings are required.



Stator

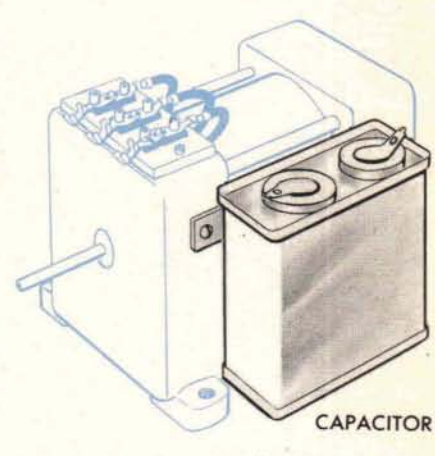
The stator consists of a cylindrical shell with slots in which the field coils are placed. There are two field coils, joined together at one end to provide a common lead to a single terminal. The other ends are left free, so that they can be led to the outer contacts of a follow-up control. The common, or center, lead is marked *C*, and the outer leads *R* and *L* (right and left).

The three leads from the stator are brought to a terminal block.

Capacitor

If no capacitor were used, and both coils of the stator were connected directly across the power supply line, the rotor of a servo motor would not revolve, but would merely remain stationary, unless actually given a push in either direction. Without a capacitor this type of motor has no starting torque of its own.

However, when current from the supply line is made to pass through a capacitor before it can reach one of the coils (while the other coil remains connected directly), the rotor will revolve. The direction of rotation will depend on which coil is supplied through the capacitor. (See page 345.)

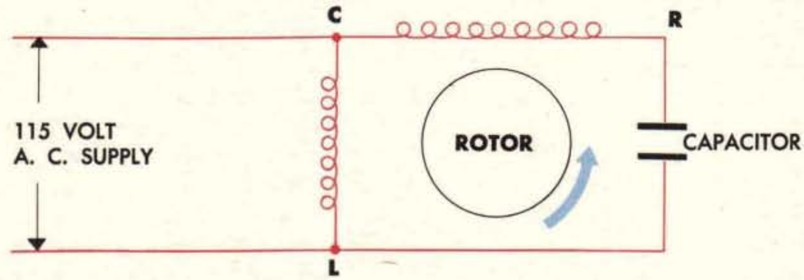


Capacitors of various sizes are used with each type of servo. However, capacitors cannot be interchanged at will. For each particular servo installation in a computer, only one particular capacitor is specified. When a capacitor is replaced, the new capacitor should be the size specified for the given installation. USE ONLY THE PARTICULAR CAPACITORS SPECIFIED FOR EACH SERVO INSTALLATION.

The capacitor is usually mounted on the side of the motor.

A servo motor must drive

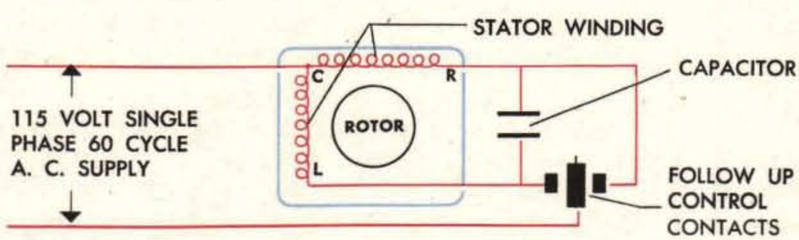
A servo motor could be connected as shown here. The *C* and *L* leads are connected directly to the power supply which puts one coil of the stator winding directly across the supply circuit. The third lead (*R*, in this case) is connected to the supply through a capacitor so that the second coil of the stator winding is connected to the supply in series with the capacitor. This arrangement produces a drive in one direction.



Although rotation of the servo motor rotor can be obtained by putting the proper capacitor in the circuit, rotatio of the rotor in one direction only is not enough. A servo motor must be able to reverse direction, in order to position shafting in response to signals of either increasing or decreasing values.

To make the servo motor able to drive in either of two directions, contact points, as shown in the diagram, are introduced into the circuit.

THE COMPLETE SERVO MOTOR HOOK-UP CAN NOW BE SHOWN LIKE THIS:



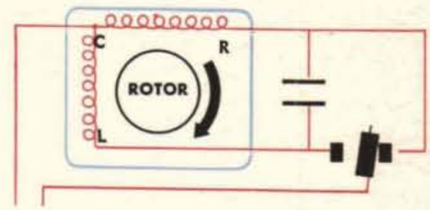
One side of the supply circuit is connected to the *C* lead at the terminal block on the motor frame, the other is connected to the inner contact on the central arm of a follow-up control. Ends *L* and *R* of the stator coils are connected to the outer contacts of the follow-up control.

The follow-up control acts to bring either the *L* or *R* contact against the center contact according to the direction the motor must drive.

in either of two directions

Clockwise rotation

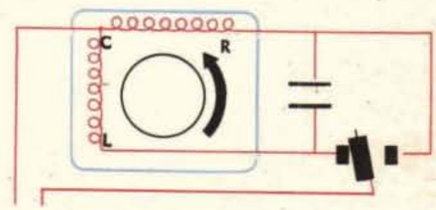
When the follow-up control completes the circuit through the righthand outer contact, the 115-volt supply is connected directly across the *R-C* leg of the stator winding, and current flows through the *R-C* coil. Current also flows through the *L-C* leg of the stator winding, but in doing so passes through the capacitor. The effect of the capacitor is to make the current in the *L-C* leg lead the current in the *R-C* leg. This results in the rotor being pulled around in a clockwise direction.



A. C. SUPPLY

Counterclockwise rotation

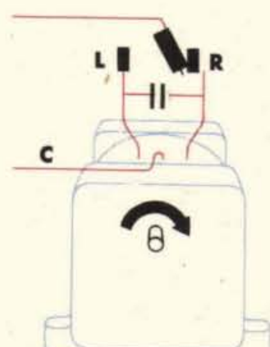
When the follow-up control reverses the contacts the 115-volt supply is connected directly across the *L-C* leg of the stator winding, and the current flowing through the *R-C* leg has to pass through the capacitor. Under these conditions, current in the *R-C* leg leads that in the *L-C* leg, and the motor is rotated counterclockwise.



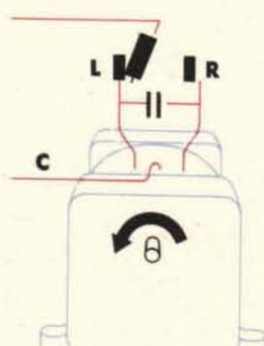
A. C. SUPPLY

Looking at the motor from the end where the stator leads come out, the action can be illustrated as shown here:

When the follow-up completes the circuit through the outer contact connected to *R*, the rotor rotates clockwise.



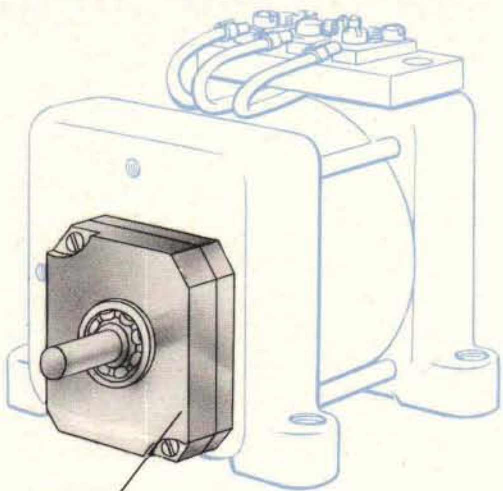
When the follow-up completes the circuit through the outer contact connected to *L*, the rotor rotates counterclockwise.

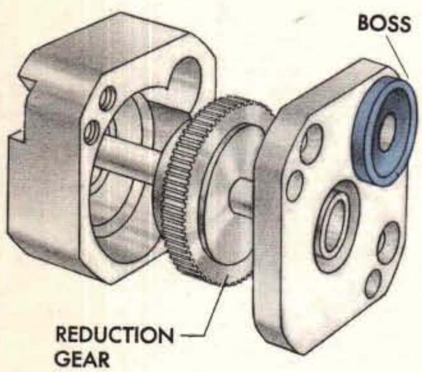


Although there are minor variations, all servo motors are essentially the same. All are required to start and stop quickly, and drive in either direction.

Instrument servo motors are so designed that they may be left energized with the driven shafting held against a limit stop (and the rotor thus held "locked") for an indefinite period without serious damage to the motor.

REDUCTION GEAR



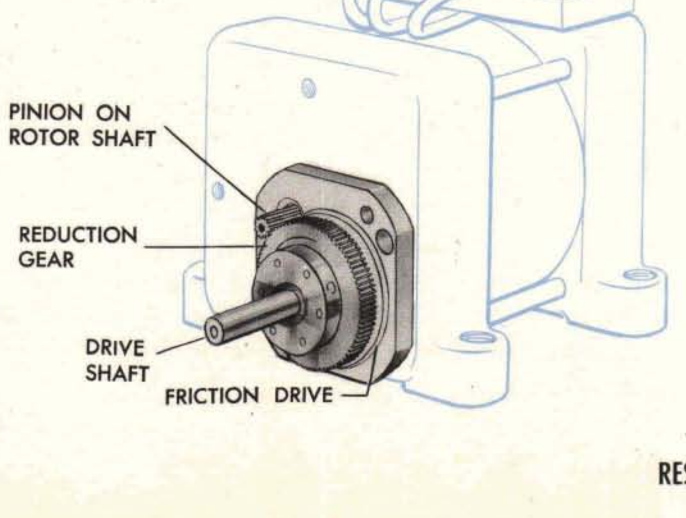


In some instances, the servo motor drives through a reduction gear.

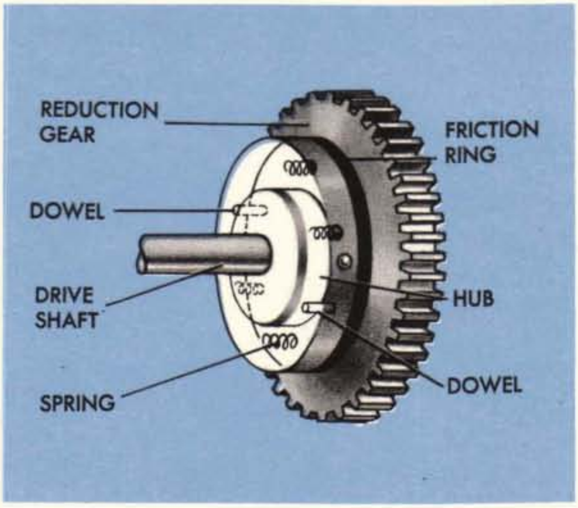
The reduction gear assembly consists of a housing in which a spur gear is mounted. In one corner of the back plate of the housing is a hole around which a boss is fitted.

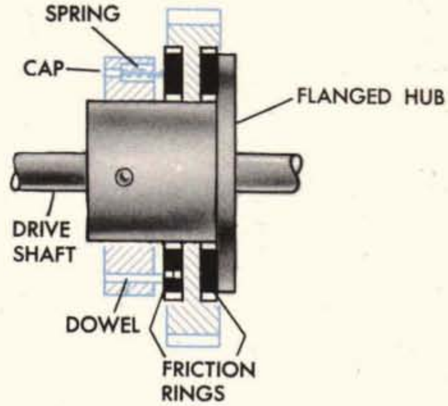
The boss fits exactly into the bearing hole in the end frame of the servo motor, positioning the spur reduction gear so that it meshes properly with the pinion on the servo rotor shaft.

The reduction gear assembly can be secured to the end frame in any one of four corner positions. This permits shifting the drive shaft to suit any particular gear connection which may be required for a particular installation.



FRICTION RELIEF

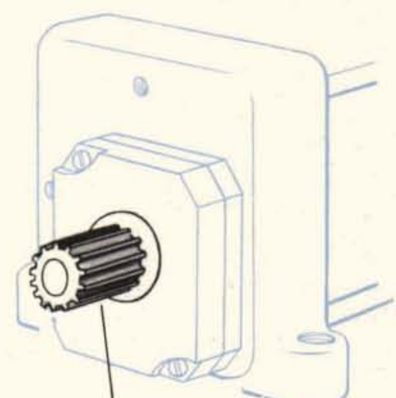




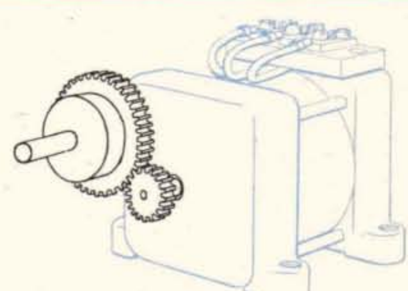
The motor drive output is transmitted through a friction relief.

On the shaft is a flanged hub. Over this hub is placed the reduction gear and two friction rings of tough but somewhat resilient material known as "phenolite." To the hub is fastened a metal cap which is drilled to hold four springs. These springs press against one of the friction rings keeping the rings and reduction gear tightly against the flange. Two dowels passing through the cap and the friction ring keep the ring rotating with the cap and shaft. Under normal loads, the drive is transmitted by the reduction gear through the grip provided by the friction rings acting under spring pressure. When the load becomes abnormal, as when the rotor shaft is suddenly stopped by a limit stop, the reduction gear slips against the rings. This slippage prevents shock, and prevents undue strain on gears, shafting, and mechanisms.

A pinion mounted on the drive shaft, outside of the housing, transmits the motor drive to other mechanisms.



The reduction gear (with friction relief) need not be mounted in a housing on the motor frame. It is often mounted externally, as shown here.

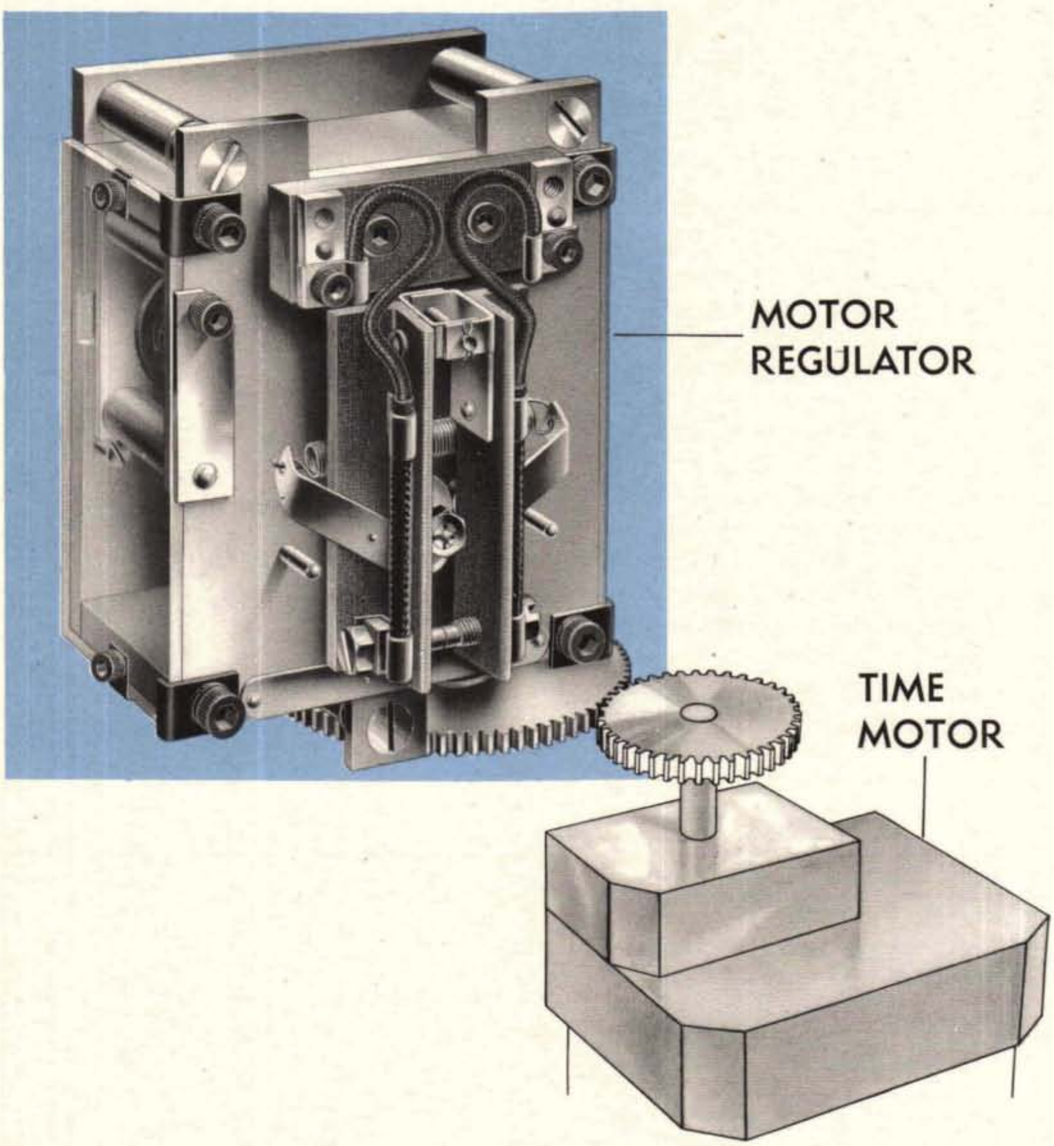


MOTOR REGULATOR

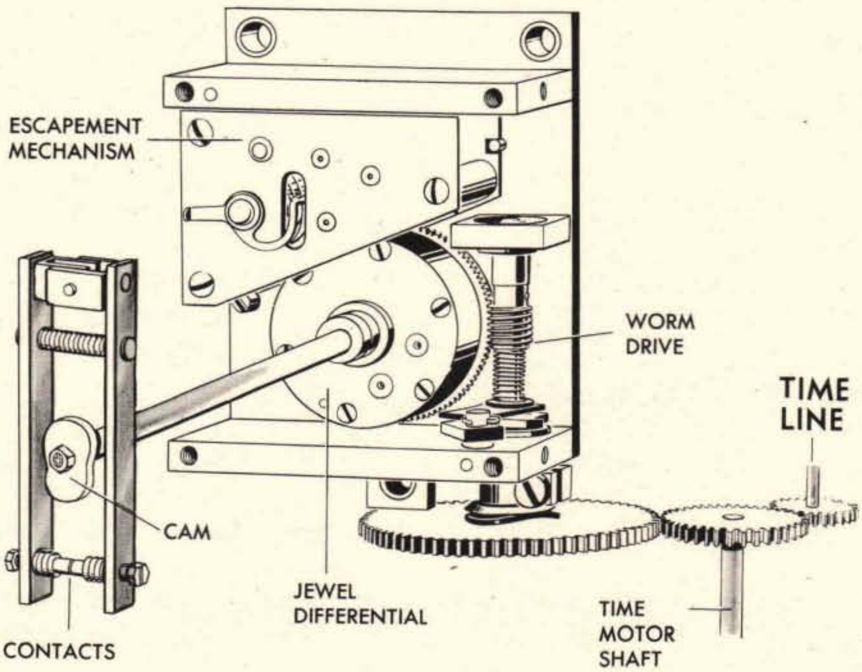
The rotation of some of the integrator disks represents TIME. They must be driven by a "time motor" at a *constant speed.*

The motor regulator is a device for keeping the time motor running at a constant speed, independent of variations in the load.

The time motor is geared to turn the "time line" too fast if power is supplied to it continuously. The motor regulator breaks the circuit when the motor begins to go too fast, and closes it again when the motor slows down, so that the motor speed is practically constant.



Here's the mechanism without its case



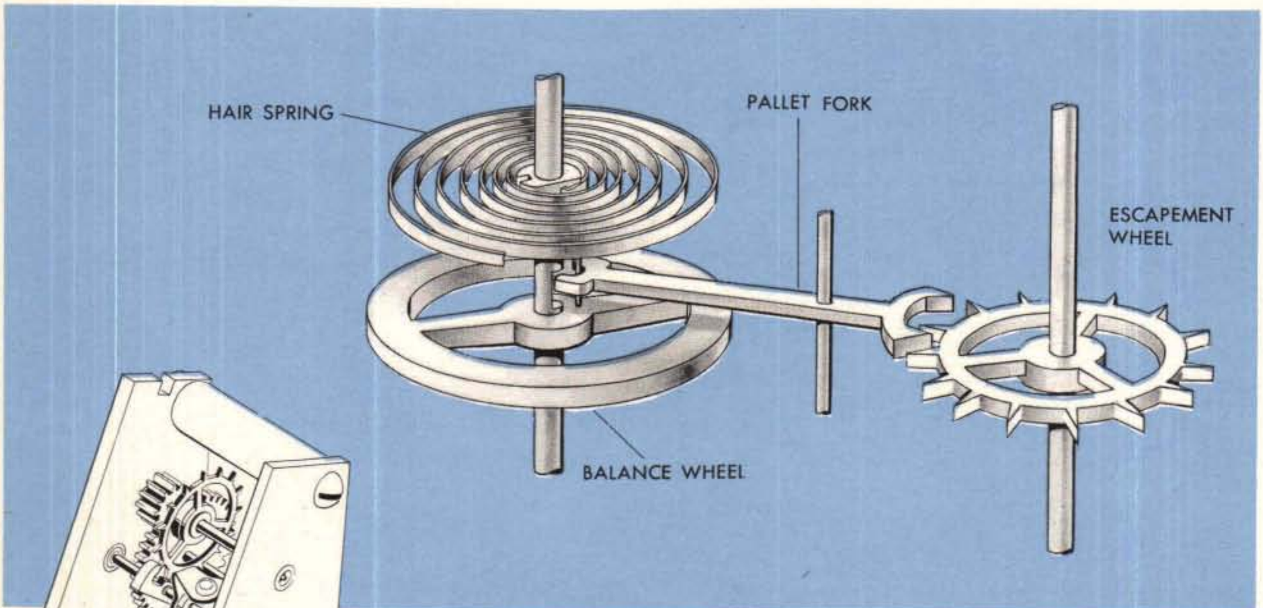
There are three main parts:

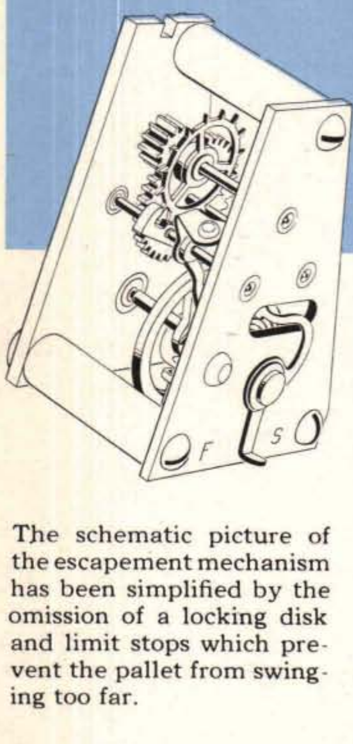
1 The Jewel Differential
2 The Escapement Mechanism
3 The Cam and Contact Assembly

The worm drive transmits the rotation of the motor shaft to the spider of the differential.

The differential compares the motor speed with the constant escapement speed. When the motor drives the spider faster than the escapement, the difference turns the cam between the arms of the "make and break" contacts.

What makes the REGULATOR tick





The schematic picture of the escapement mechanism has been simplified by the omission of a locking disk and limit stops which prevent the pallet from swinging too far.

The ESCAPEMENT MECHANISM

The escapement mechanism works like the escapement in a watch. The principal parts are the escapement wheel, pallet, balance wheel and hair spring.

The escapement wheel is the input.

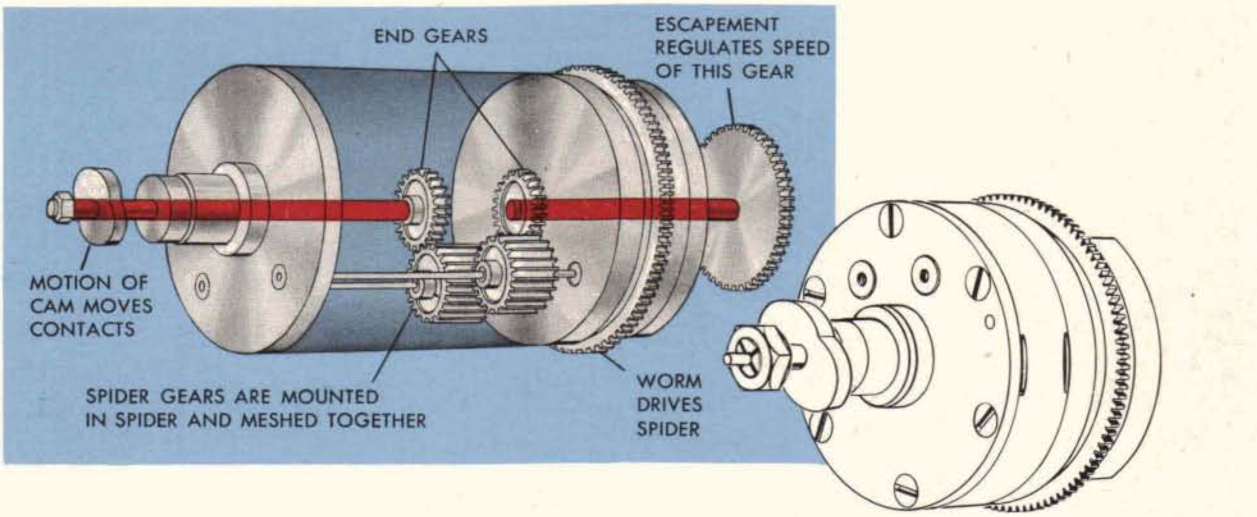
Rotation of the escapement wheel swings the pallet around its pivot staff until it locks against a tooth in the escapement wheel.

As the pallet swings it moves the pin in the balance wheel. This movement rotates the balance wheel and winds up the hair spring.

Winding the hair spring slows up, stops, and then reverses, the rotation of the balance wheel. The pin in the balance wheel now swings the pallet in the opposite direction.

This opposite pallet movement allows the locked escapement wheel tooth to escape and the cycle is repeated.

The pallet movement is controlled by the even rhythm of the balance wheel and hair spring. This rhythm holds the escapement wheel input to a constant average speed.



The JEWEL DIFFERENTIAL

This spur gear differential is known as a jewel differential because the gears run on jewel bearings. The jewel bearings reduce friction drag to a minimum.

The spider in this differential is a housing that encloses the end gears and spider gears. This spider is driven by the time motor through a worm input.

One side of the differential is geared to the escapement mechanism. The other side drives the cam.

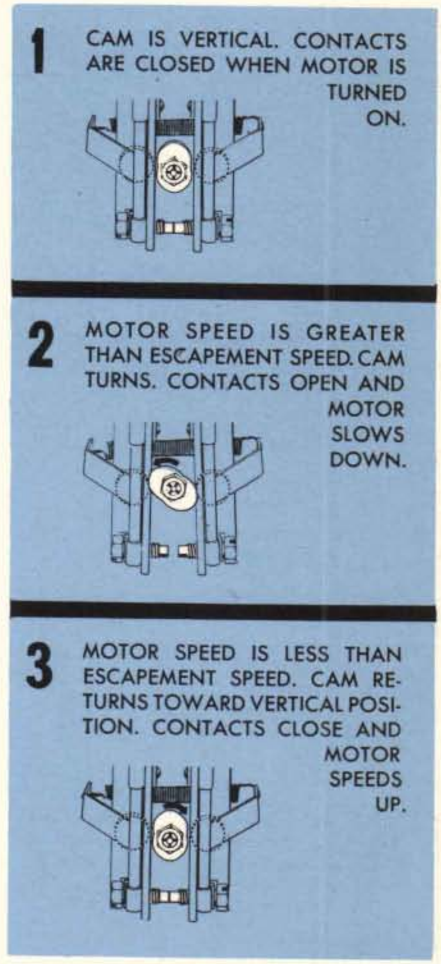
When the motor is running, the spider turns and drives the side of the differential geared to the escapement mechanism.

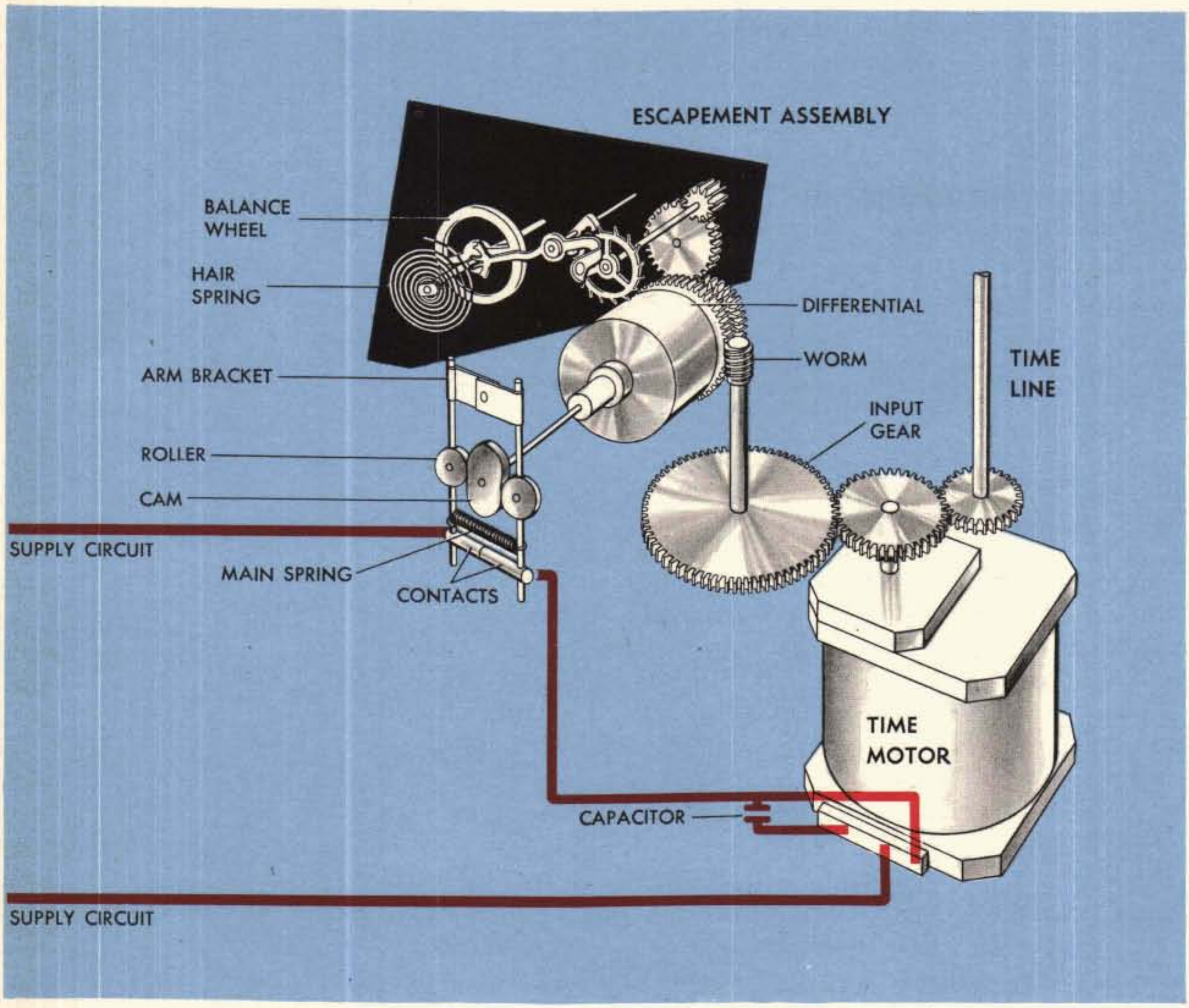
The escapement mechanism tends to turn at a CONSTANT speed. The motor speed varies. The *difference* between these speeds drives the output side of the differential and turns the cam.

The cam turns between two rollers on the arms holding the contacts. These arms are held together by a spring.

When the MOTOR SPEED IS *GREATER* THAN THE ESCAPEMENT SPEED, the cam turns and spreads the contact arms. This OPENS THE CONTACTS, and the motor slows down.

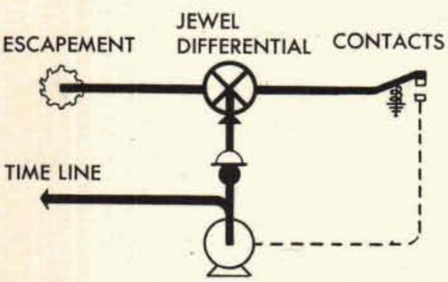
When the MOTOR SPEED IS *LESS* THAN THE ESCAPEMENT SPEED, the cam turns the other way, returning to its up-and-down position. The SPRING ON THE CONTACT ARMS CLOSES THE CONTACTS. The motor speeds up again.





Here's how it works

Here is the motor regulator unit hooked up with the time motor. When the motor is turned on, the following things happen almost instantaneously:

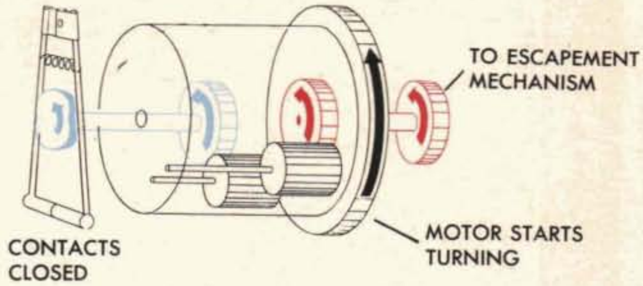


1 Since the contacts are closed, current goes through them to the time motor.

2 The worm on the input shaft turns, driving the spider of the differential.

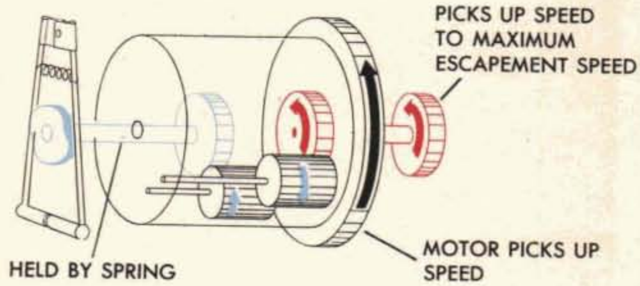
3 The cam begins to turn.

4 Almost immediately the cam hits the rollers on the contact arms. The spring acts as a slight brake so that the contacts do not open at once.

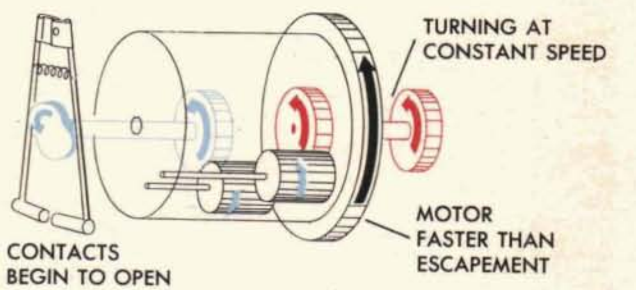


5 Following the line of least resistance, the motion from the spider backs into the escapement mechanism which picks up speed.

6 Meanwhile the time motor has been picking up speed. Soon the escapement mechanism is moving at the maximum speed that the coiling and uncoiling of the hairspring will allow.

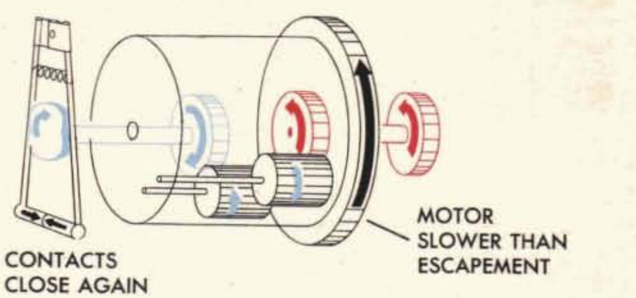


7 When the rotation of the spider can no longer back into the escapement, it turns the other side of the differential on which the cam is fastened. The contacts open.



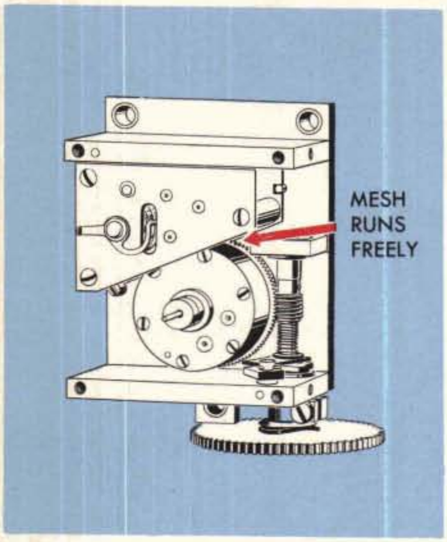
8 The motor slows down a little.

9 As soon as the motor speed falls a little below the escapement speed, the cam will no longer hold the contacts apart. The mainspring will bring the arms together, turning the cam toward its vertical position and bringing the contacts together once more. The cycle then starts over again.



The cam is continuously opening and closing the contacts as the motor speed becomes slightly greater or less than the escapement speed.

This happens so fast that the motor speed is always closely matched with the escapement speed. *The average speed of the motor output shaft is constant.*



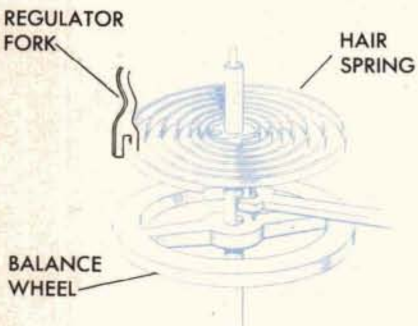
Adjusting the MOTOR REGULATOR

Before any individual part of the Motor Regulator is adjusted, check the complete Motor Regulator Unit. In this way, trouble that would require replacement of all or part of the unit may be located.

First check that the differential runs freely, and that the mesh between the differential and the escapement is free. The lost motion between the differential and the escapement should be between .005 and .010 as measured on the pitch line. For instructions on adjusting lost motion see OP 1140A.

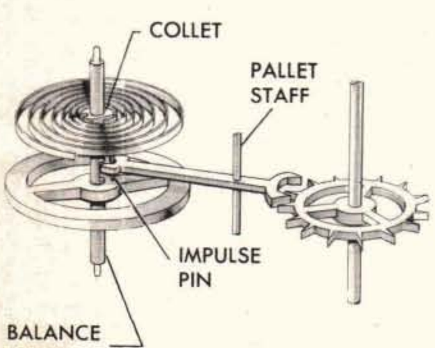
Then check the escapement:

1 Be sure that the escapement does not lock when the cam is rotated past its peak. Also make certain that the cam is smooth.



2 With the balance wheel at rest, the outer turn of the hair spring must remain in the center of the regulator fork when the regulator lever is moved through its full travel.

3 The spacing between the turns of the hair spring must be uniform. Coils must not touch each other when the balance wheel is rotated to its extreme positions. The hair spring at its maximum extension must not touch any part of the assembly other than the inside faces of the regulator fork.



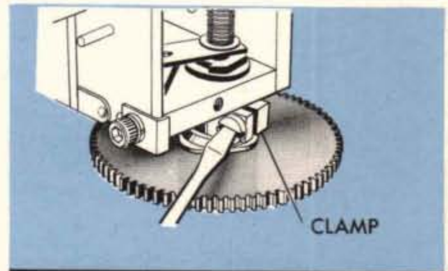
4 The impulse pin must be in a line with the centers of the balance and the pallet staffs when the balance wheel is in free normal position. If necessary to adjust, slip the hair spring collet on the balance staff. Hold the collet and rotate the balance staff until the pin is in line with both staffs. This adjustment should not be attempted by inexperienced personnel.

5 The escapement must be self-starting at all times and must run backward under slight finger pressure on the escapement wheel.

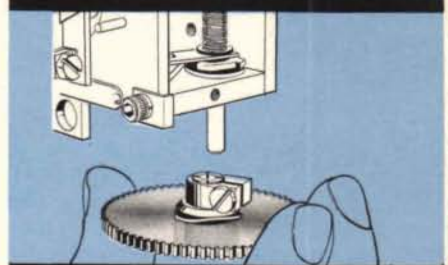
If any of these steps shows the regulator to be out of order, it must be replaced or repaired. If the motor regulator passes these check tests but is still out of time it should be adjusted.

Adjusting the friction relief

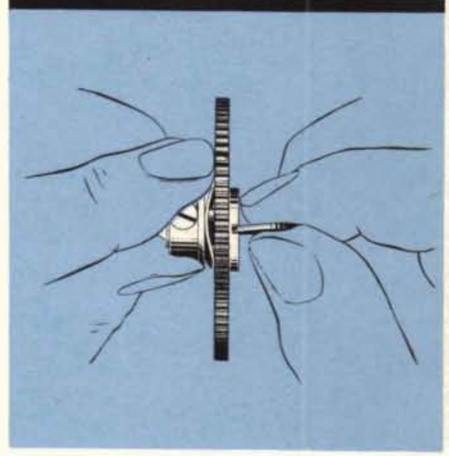
The friction on this gear may be too loose, allowing it to slip on the shaft instead of driving the differential. If it is slipping, it is changing the value of the input to the differential.



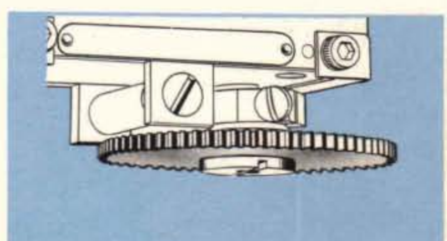
First check the clamp, which may have worked loose. If it is loose, tighten it. If the clamp is all right, but the gear is still slipping, remove the Motor Regulator from the Computer. Then loosen the clamp and remove the gear from the shaft. Use a penny in the slot in the flange on the under side of the gear.



Hold the clamp as shown and hand-tighten the gear with two fingers of each hand. Do not get it too tight, because if the time line of the motor should reverse with the gear too tight, the stop assembly would jam and break.



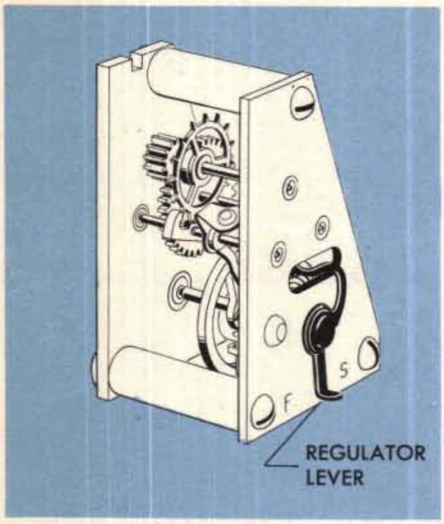
When replacing the gear on the shaft, do not set it too far up. Tighten the clamp and replace the regulator in the computer.



If the input gear has worked up too far on the shaft, it will rub against the edge of the regulator plate. Re-adjust the gear on the shaft by loosening the clamp and lowering the gear. Then tighten the clamp.

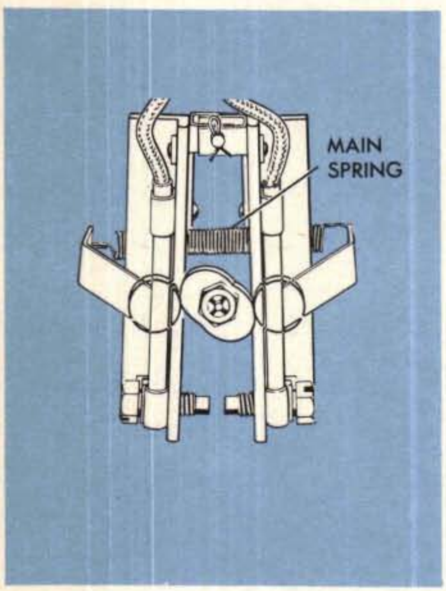
Timing the MOTOR REGULATOR

The Motor Regulator speed should be accurately timed, using a stop-watch to check the time dial driven by the Time Motor. If the timing is out the Motor Regulator can be adjusted. There is a motor regulator test prescribed for each installation, which specifies the timing procedure and the allowable error.



The regulator lever

The regulator lever, an adjustment arm on the clock escapement mechanism, is provided to adjust the escapement's speed. When moved toward *F*, the motor speed is increased. The lever is easily reached by loosening the screw holding the small cover on the front panel. If the lever has been moved to its limit of *F* or *S* and the motor still runs too slow or too fast, then the main spring must be adjusted.



The main spring

Sometimes it is possible to alter the timing slightly by changing the tension of the mainspring.

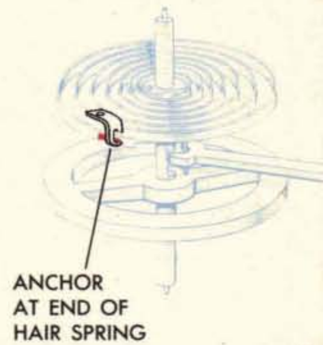
The main spring is located between the contact arms. The arms holding the mainspring should always be tight. If they become loose, the whole contact assembly should be replaced. The mainspring can be stretched in order to slow down the regulator, or shortened to increase the speed. The mainspring may be lengthened or shortened 1/16 inch—*no more*. Some models have an anchor adjustment on the mainspring which is used to shorten or lengthen the mainspring. Where no anchor adjustment is provided, the mainspring may be lengthened. To lengthen: Unhook one end of the mainspring from the arm and stretch it a little at a time. Anchor it again. If the mainspring needs to be shortened, it must be replaced with a shorter one.

If the adjusting lever and the mainspring adjustments fail, replace the escapement. See O P 1140A for instructions.

The hair spring

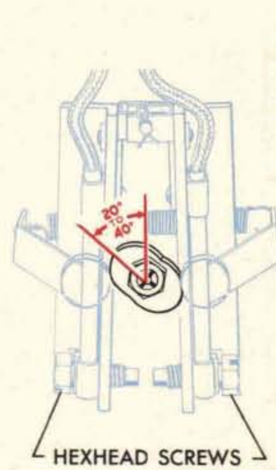
This adjustment should only be made when escapement replacements are not available.

Adjusting the hair spring is a delicate operation and it should be adjusted a little at a time to avoid over-adjustment. *Be very careful not to bend the hair spring.* Lengthening the hair spring will cause the motor to slow down, and shortening the hair spring will cause the motor to speed up. First set the regulator lever in the center between *F* and *S*. Loosen the hair spring from its anchor and lengthen or shorten it as required; then re-clamp it in the anchor. Remember to move the hair spring only a little at a time until the timing is correct. Whenever the hair spring length is changed the collet must be turned on the balance staff to line up the impulse pin and the balance and pallet staffs as described on Page 214. To simplify the hair spring adjustment, the hair spring on later models is held in the anchor by a locking screw.



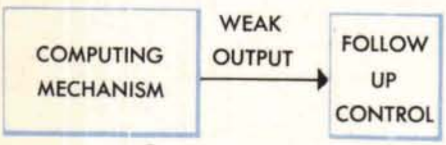
Adjusting the contacts

To adjust the contacts turn both the hexhead screws until the cam has to rotate between 20° and 40° before the contact is broken. This will leave about 1/16 inch clearance between the rollers and the cam when the cam is in its normal position and the regulator is at rest. Some models have no contact adjustment because they have already been properly spaced at the factory.

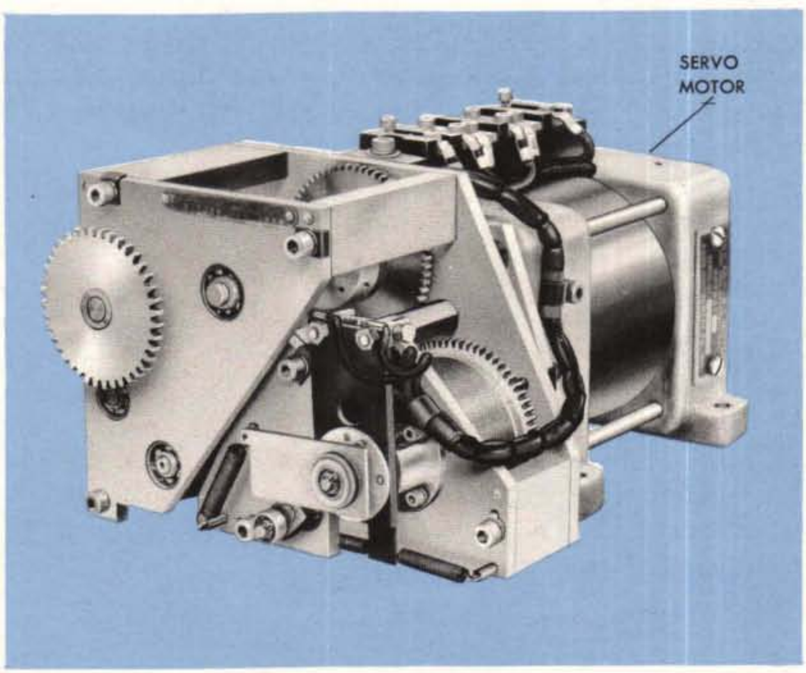


FOLLOW-UP CONTROLS

Computing mechanisms are not designed to drive heavy loads. The outputs from such mechanisms often merely *control the action of servo motors.* The motors do the actual driving of the loads which have to be handled.

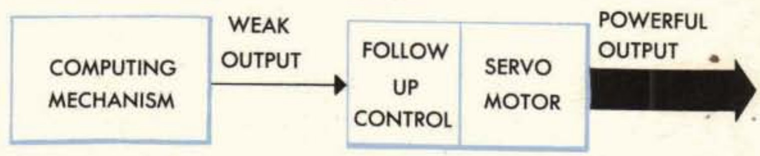


The device which makes it possible for the comparatively weak output from a computing mechanism or any other source to control the action of a servo motor is called a *follow-up control.*

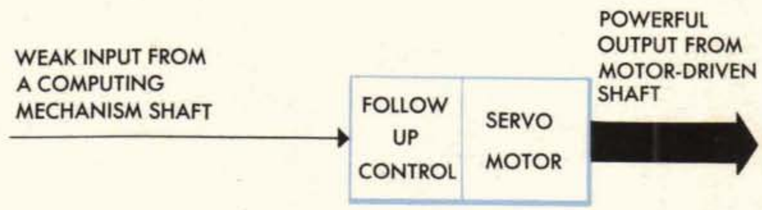


THIS IS A VELOCITY-LAG TYPE OF FOLLOW-UP CONTROL MOUNTED ON A SERVO MOTOR

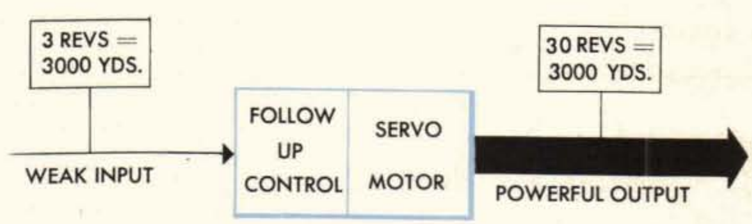
The follow-up control and the servo motor together provide a means of "boosting," or increasing the *weak* output from a computing mechanism into a *powerful* output capable of moving gear trains and shafting rapidly and accurately.



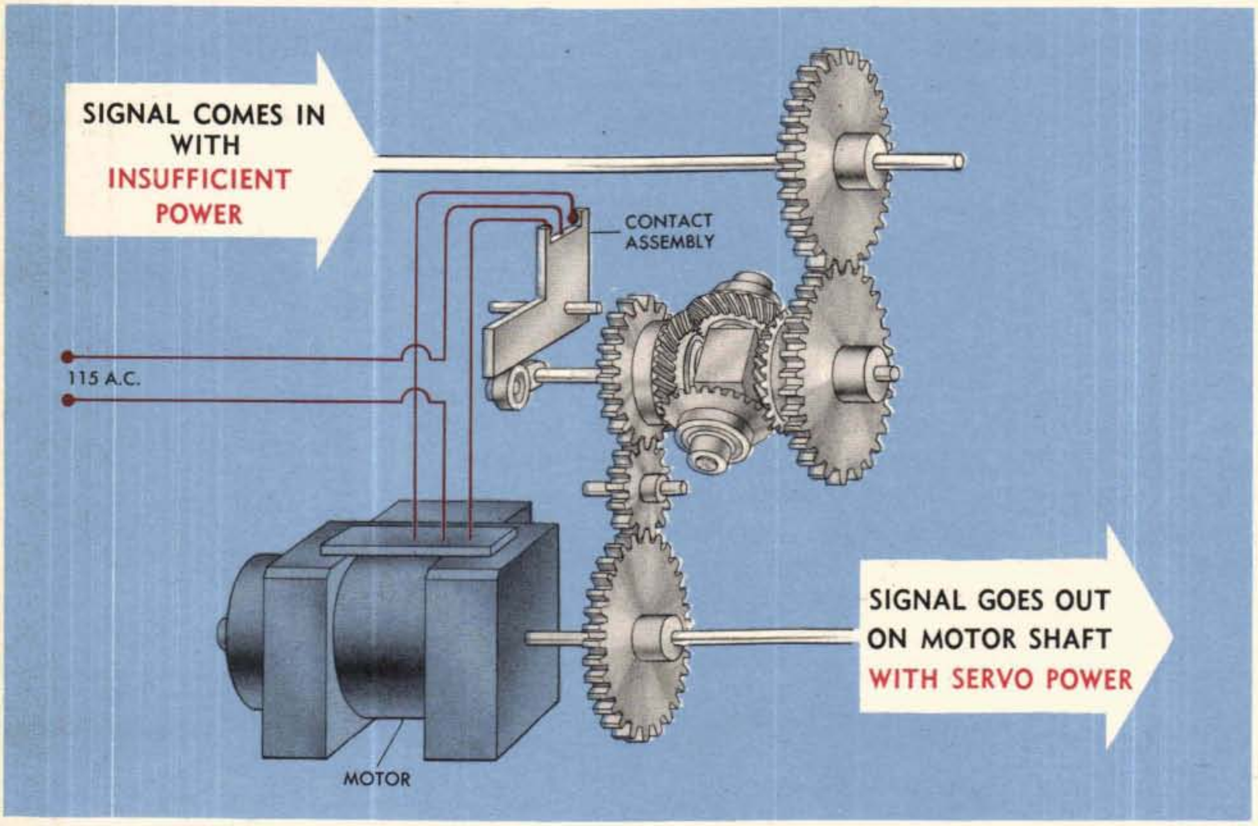
The output from a computing mechanism is considered to be the input to a follow-up control. The hook-up may be pictured this way: The weak output of a computing mechanism is applied as input to a follow-up control. A servo motor drives the output shaft with considerable power.



The follow-up control regulates the action of the servo motor in such a way that the position of the output shaft always represents the value of the quantity set into the control by the input shaft. For example, suppose one revolution of the input shaft represents 1000 yards, and one revolution of the output shaft represents 100 yards. Then if the input shaft makes 3 turns (with little power), the output shaft makes 30 turns (with much greater power).

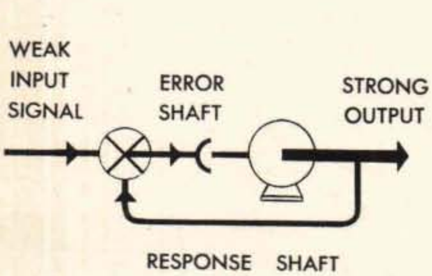


These are the elements



This is a simplified form of follow-up control which will be used to illustrate the general principles of operation of all follow-up controls.

THE DIFFERENTIAL

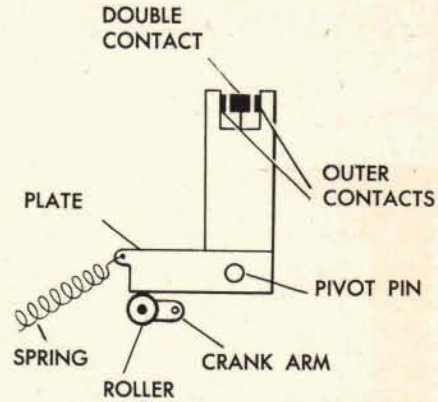


THE ELEMENTS OF A FOLLOW-UP CONTROL ARE OFTEN REPRESENTED SCHEMATICALLY AS SHOWN HERE.

The differential is used to measure the difference, or "error," in position between the input and the output. The input is geared to one side of the differential. The servo output is used to do two things: (1) to position whatever mechanism is being handled, (2) to drive the other side of the differential. This second operation is known as the servo "response."

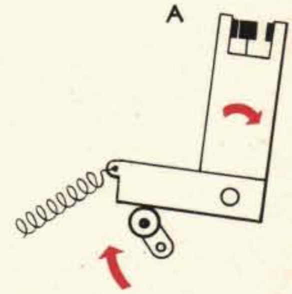
When there is a difference between the input and the output, the spider of the differential turns. As this happens, the spider shaft operates a set of contacts which control the action of the servo motor in such a way that the motor drives its side of the differential in the opposite direction to that taken by the input. That is, the servo always drives to reduce the difference, or error, to zero.

# of a FOLLOW-UP CONTROL



The contact mechanism

The contact mechanism consists of a vertical arm carrying two contacts known as the "outer" contacts. To the base of the arm is fastened a plate projecting to one side. Arm and plate pivot on a pin. Beneath this assembly is a small crank-arm, attached to the differential spider shaft, and at one end of the crank arm is a roller.



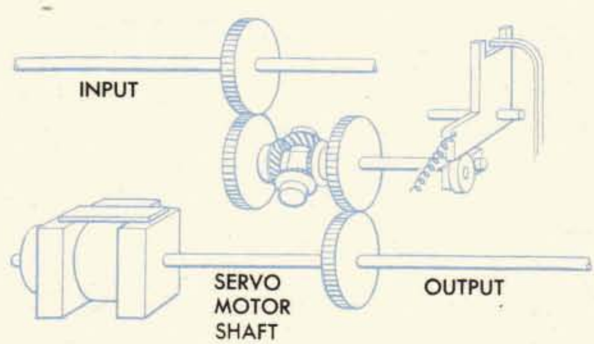
In normal position, the crank-arm is horizontal, and a spring causes the base plate of the contact arm to bear against the roller, holding the contact arm in a vertical position.

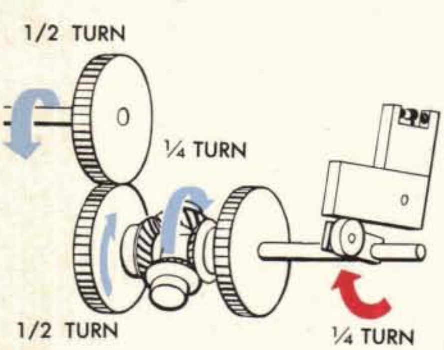
Mounted midway between the outer contacts is a center (double) contact.

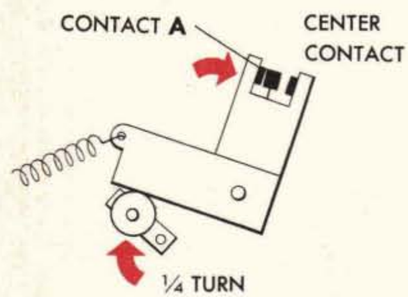
If the crank-arm turns clockwise, it rotates the outer contact arm clockwise (opposing the action of the spring). This brings the outer contact *A* against the center contact.

If the crank-arm rotates counterclockwise, the roller ceases to bear against the base of the outer contact arm, and the arm is rotated counterclockwise by action of the spring. This brings the outer contact *B* against the center contact.

When contact is made by *A*, the motor runs in one direction; and when contact is made by *B*, it runs in the opposite direction. In order to simplify the schematic representations which follow, the follow-up control input shaft is geared to the left side of a differential, and the servo motor shaft is geared to the right side of the same differential by a 1:1 gear ratio. Actually this gearing is seldom 1:1.







The FOLLOW-UP at work

Suppose the follow-up input turns ½ a revolution. This will drive the left side of the differential ½ turn.

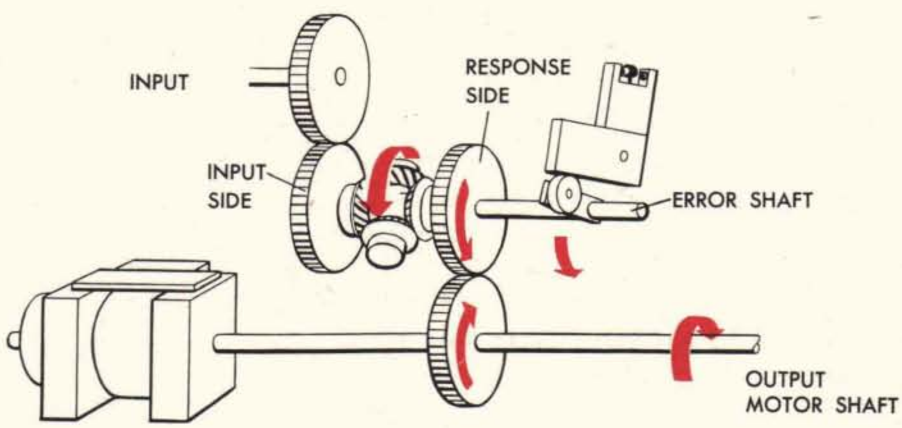
The left side rotates the spider, because the right side of the differential is geared to the servo and held stationary.

Since the input was ½ turn, the spider turns ¼ turn (in this case clockwise) and rotates the crank-arm ¼ turn (clockwise).

This causes the outer contact arm to be rotated, and the outer contact *A* is brought against the center contact.

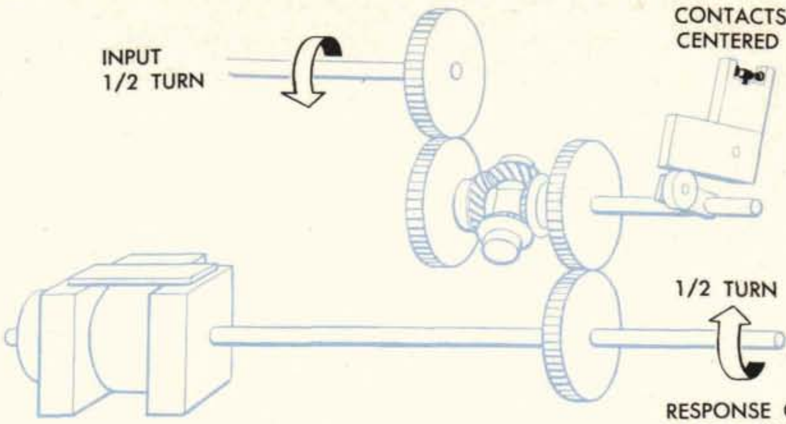
Turning on the motor

When contact is made, the power supply is connected to the motor in such a way that the motor turns in a direction opposite to that of the input, as shown here:



The motor will run as long as the contacts are closed, and will turn the right side of the differential. This action of the servo is the "response." It causes the spider to be rotated back towards its original position, which in turn causes the crank-arm to be rotated counterclockwise, back towards its original position.

As the crank-arm rotates and reaches its normal position, the spring pulls the outer contact arm back to the vertical position. This opens the contacts and shuts off the power.



THE FOLLOW-UP HAS OBEYED THE SIGNAL. THE OUTPUT IS NOW SYNCHRONIZED WITH THE INPUT

Since the crank-arm is back to its starting point, it has been rotated back ¼ turn. The spider that drives it has therefore also been rotated back ¼ turn.

And since the spider has been driven back ¼ turn, the right (response) side of the differential has been driven back ½ turn. This means that the motor shaft, being geared to the right side by 1:1 ratio gearing has also rotated ½ turn—which is *the same amount as the input shaft rotated.*

In this way, the number of revolutions (or fractions of a revolution) of the servo shaft corresponds exactly with the number of revolutions (or fractions of a revolution) of the input shaft from the computing mechanism. So the final position of the motor-driven output shaft corresponds exactly with that of the input from the computing mechanism.

In this way the comparatively weak output from the computing mechanism can be transmitted in powerful form and made to overcome the loads required for operation of other units.

This is the simplest form of follow-up control, and it illustrates the basic principles governing the operation of follow-up controls generally.

The device has been described as if the input had rotated only ½ turn. However, if the input rotates *continuously* it will keep closing the contacts, and the motor will drive continuously to open the contacts, moving the output shaft to keep up with the input.

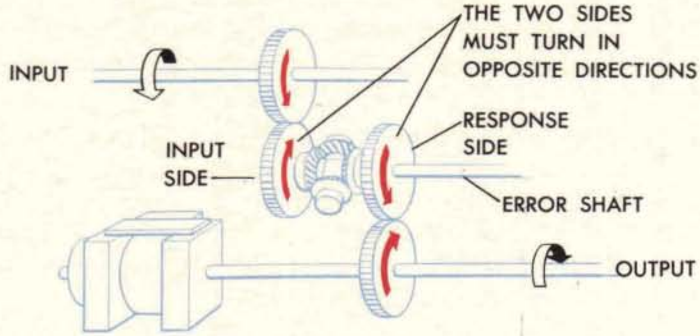
Until the motor has driven sufficiently to make output equal to input, the input side of the differential has, of course, been driven more than the response side. There is a difference or error between input and output values. When both sides of the differential have been driven an equal amount, output synchronizes with input. This is "the point of synchronism," or "point of zero error."

The spider of the differential always measures the error between input and output. Therefore the spider is called the "error shaft." When input and output are synchronized, there is no error, and at this point the spider is back at the position from which it started.

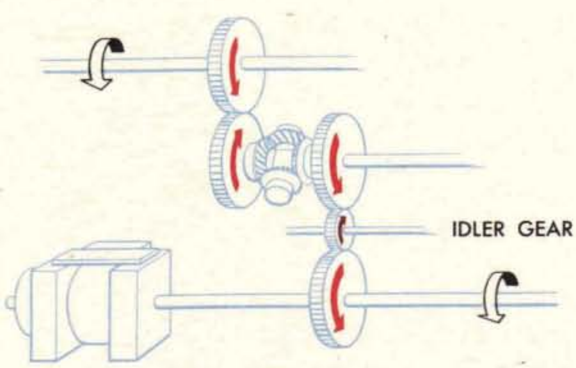
The sides of the differential must turn in OPPOSITE directions

It is not important whether the servo response shaft turns in the same direction as the input shaft or not. The important fact is that the servo response shaft shall be so geared to its side of the differential that *the response will be rotated in the opposite direction to that taken by the input side.*

This means that the servo motor shaft can either be geared to the differential in the manner already shown, which is like this:



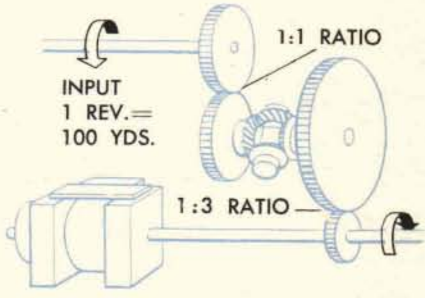
—or, if the output shaft is run in the opposite direction, like this:



Both these methods cause the response side of the differential to rotate in the opposite direction to the input side.

Other gear ratios can be used

For the sake of simplicity, gearing has been shown as 1:1 ratio throughout. This is not usually the case.



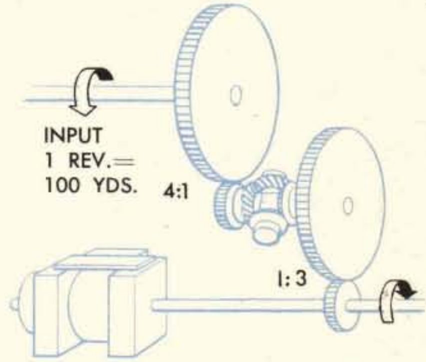
As long as the positions taken by the output shaft represent the values of the quantities set into the control by the input shaft, the gear ratios in the line can vary.

If, for example, 3 revolutions of the output shaft represent 100 yards, and only one revolution of the input shaft represents 100 yards, proper gear ratios will provide for rotating the output shaft 3 times for each revolution made by the input shaft.

If a greater reduction is needed, there may be gear ratios on both the input and output sides of the differential.

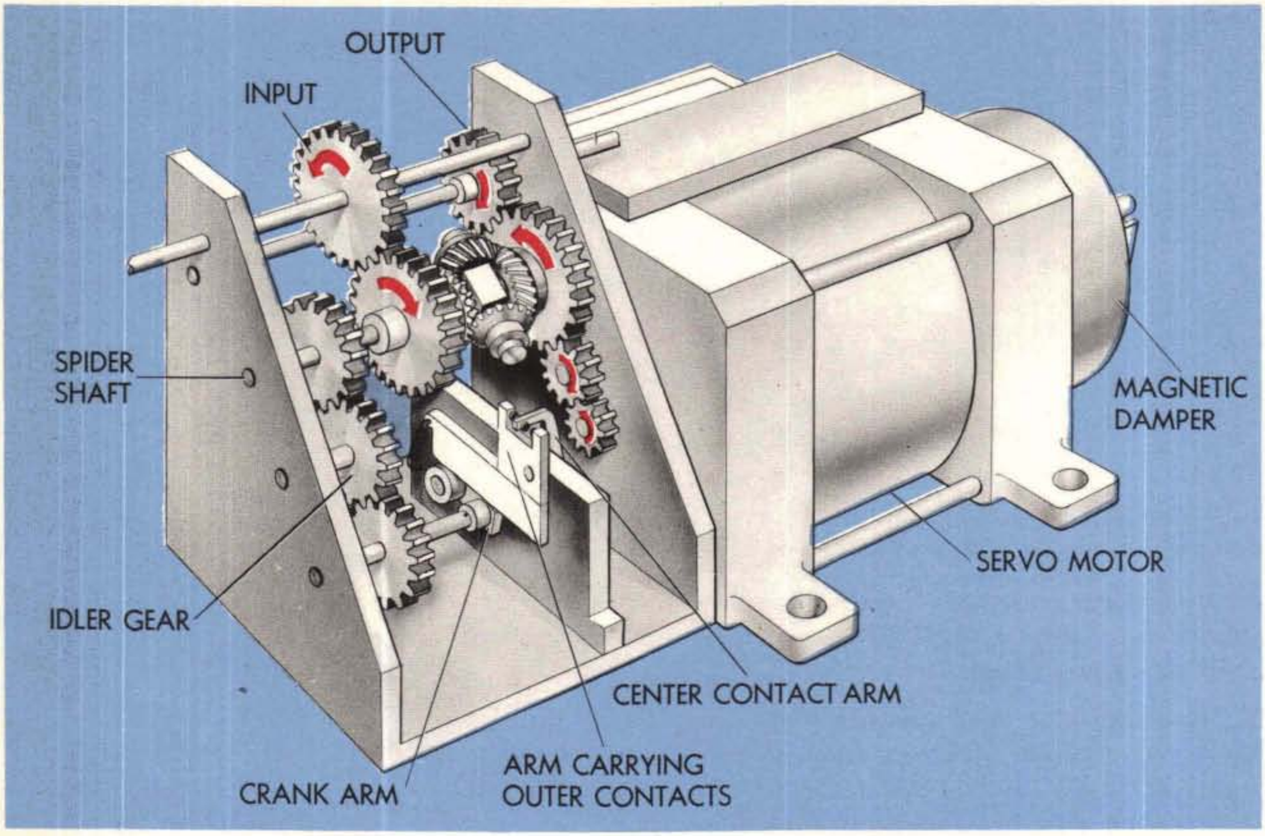
Whatever the ratios the follow-up will synchronize when the TWO SIDES OF THE DIFFERENTIAL have turned equal amounts.

Here, for example, 1 revolution of the input shaft and 12 revolutions of the servo output shaft both represent 100 yards. The input shaft turns one side of the differential through 4:1 ratio gearing. The servo output shaft turns the other side of the differential through 1:3 gearing.



Assume that the input shaft turns 1 revolution. It will turn its side of the differential 4 revolutions. The servo output must now drive until it turns the other side of the differential 4 revolutions. Since the servo shaft in this example must turn 3 revolutions in order to turn its side of the differential 1 revolution, it must turn a total of 12 revolutions to turn the differential 4 revolutions.

So each revolution of the input will cause the servo output to drive exactly 12 revolutions. The 12 revolutions of the motor output shaft represent the same 100 yards which are represented by 1 revolution of the input shaft.

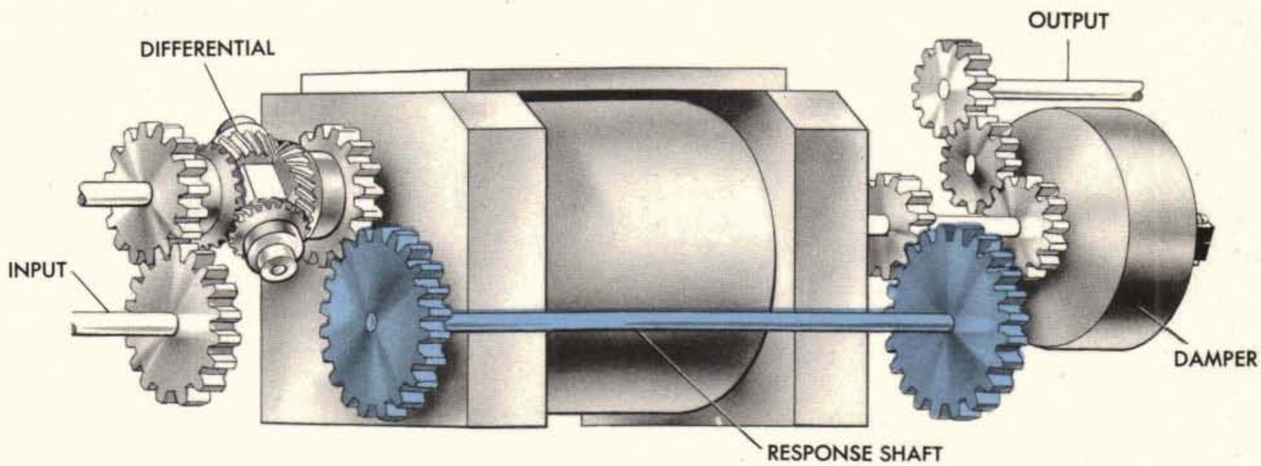


Here is a follow-up ASSEMBLED

The elements of a follow-up control are mounted so that the device will take up as little space as possible and may be installed rapidly at any point in the computer.

The elements are often assembled as shown above. This is not an actual follow-up assembly. The gearing has been spread out for the sake of clarity. In this arrangement, the crank-arm controlling the contacts is driven by the spider of the differential through an idler gear.

Other elements are easily added to this form of assembly, permitting the most complete type of follow-up control to remain a compact unit.



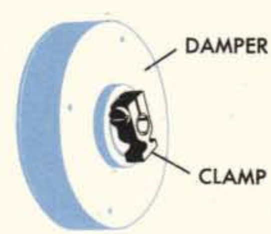
Output and input may be at OPPOSITE ENDS of the servo

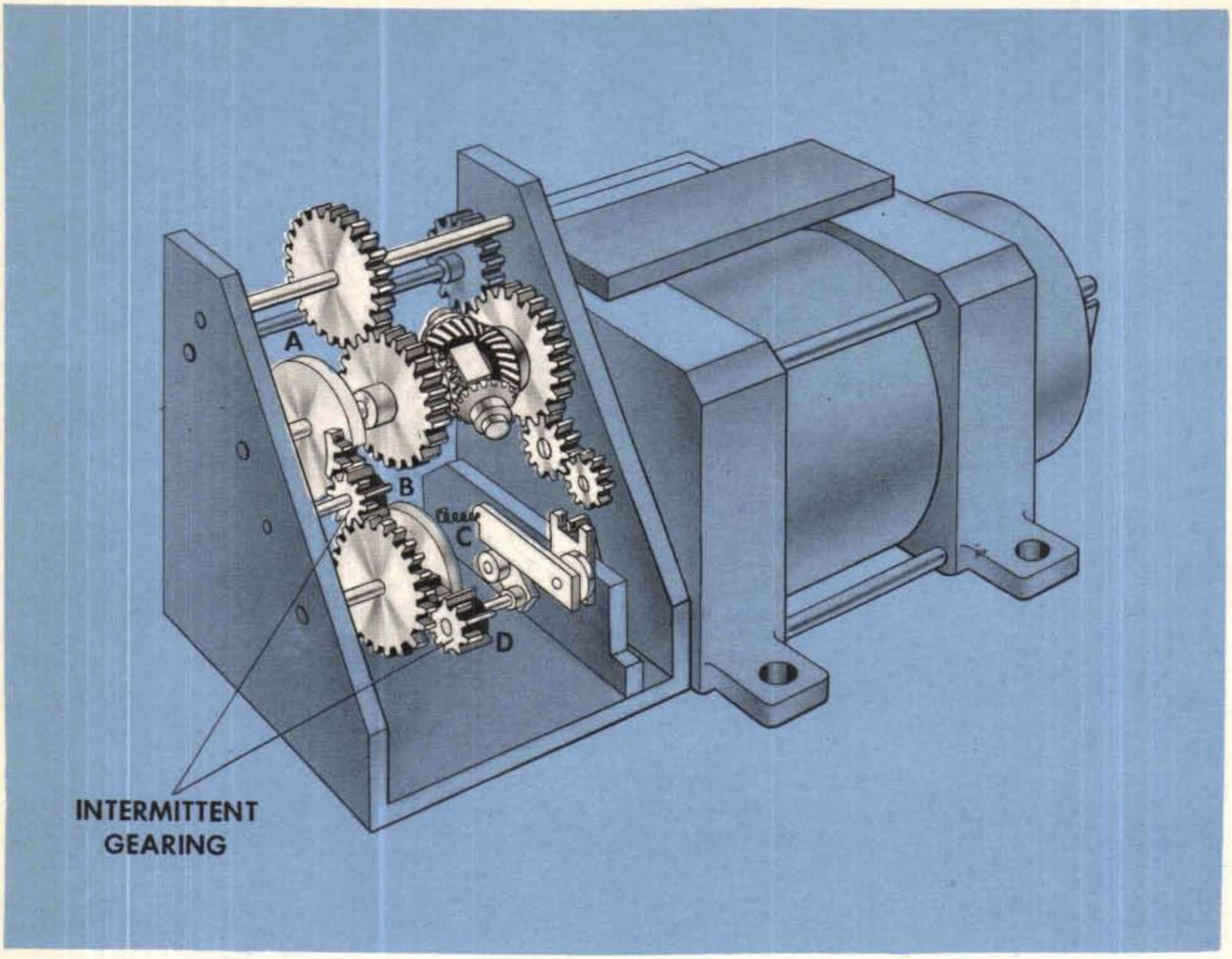
Usually the differential and the output drive shaft are at the same end of the servo motor. In some assemblies the drive is taken from the other end of the motor and transmitted to the differential and contact assembly by a long shaft.

However the parts of a follow-up are arranged, the principles of operation are always the same.

Sometimes a magnetic damper is used

After the servo has synchronized on a fixed signal, it tends to oscillate a little back and forth across the point of synchronism. When a damper is placed on the rotor shaft, it reduces the oscillations by resisting sudden starts or reversals of direction of the rotor. The chapter on the Magnetic Damper, page 334, describes damper action in detail.





The INTERMITTENT GEARING

The majority of follow-up controls employ "intermittent" gearing. This type of gearing permits the input shaft to make many revolutions in relation to the shaft which carries the crank-arm.

This gearing has two purposes:

1. An input may come into a follow-up control faster than the servo can convert it into an output. When this happens, the extra input is "stored" in the intermittent gearing until the servo output can catch up.
2. When a servo is shut off, the input is stored in the intermittent gearing until the servo motor is energized.

This gearing is so constructed that while the input is driving continually, the output from the intermittent gearing drives a fixed small amount and then remains stationary. The input must turn a certain amount before the output moves again.

The intermittent gearing used in follow-ups is not to be confused with the gearing of the Intermittent Drive.

Intermittent gearing works like this

Gear *A* is a "sector gear," having only two teeth.

Gear *B* has 8 teeth, every other tooth being partly cut away. This type of gear is called a mutilated pinion.

If gear *A* starts from the position shown and turns one revolution, it will turn gear *B* only two teeth, or ¼ of a revolution.

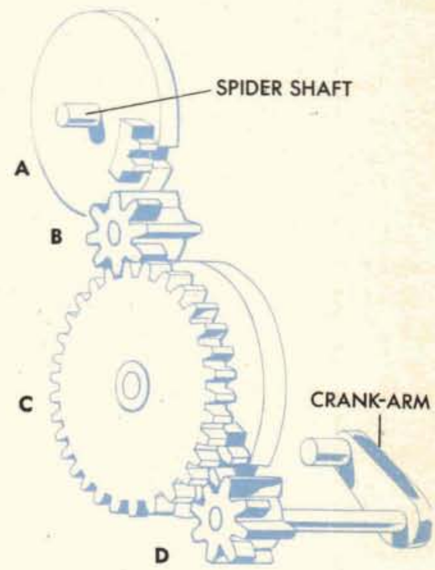
Gear *B*, therefore, turns once for every 4 revolutions of the spider shaft.

Gear *C* has 40 teeth. This gear turns once for every 5 revolutions of the small 8-tooth gear, *B*, or once for every 20 revolutions of the spider shaft.

Gear *C* has a 2-tooth "sector" gear which meshes with a second 8-tooth gear *D*. One revolution of *C* turns gear *D* ¼ turn.

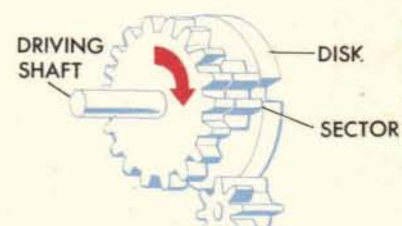
But *D* is fixed to the shaft which rotates the crank-arm, so that one revolution of *C* rotates the crank-arm ¼ turn.

In this way rotating the input a small fraction of a revolution, with both sectors meshing, will move the crank-arm ¼ turn. The crank-arm will then remain at this new position for 20 revolutions of the spider shaft or 40 revolutions of the input shaft. After 40 revolutions of the input shaft both sectors will again be in mesh at the same time and the crank-arm will again rotate ¼ turn.

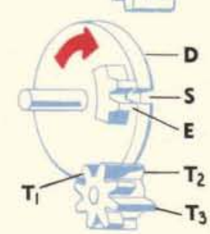


A close-up of the action

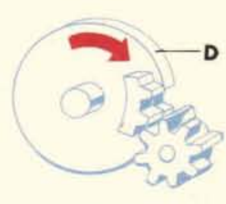
The "sectors" are mounted on disks. Sometimes the disks are joined to the gears which drive their shafts. Sometimes the disks are separate from their driving gears. In either case the action of the "sectors" is the same.



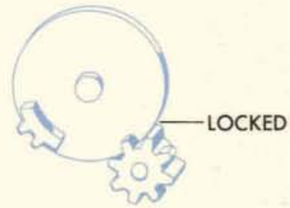
When the disk is rotated, the lower edge of tooth *E* comes against the small tooth T_1 on the small gear, and forces the small gear around ⅛ revolution.



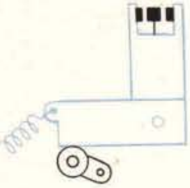
As the disk continues rotating the long tooth T_2 enters slot *S* in the disk. The second sector tooth forces the small gear to rotate an additional ⅛ revolution.

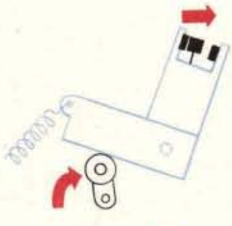


After the ¼ turn of the small gear, the smooth edge of the disk *D* rides against the long teeth T_2 *and* T_3, keeping them "locked" in one position. Because of this locking effect, there can be no further movement of the small gear until the two teeth of the sector gear travel through one complete revolution.



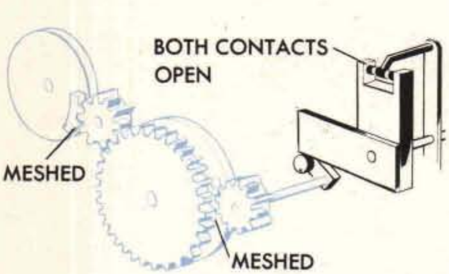
Why intermittent gearing





CORRECT CONTACTS CLOSED FOR CLOCKWISE MOTION OF CRANK-ARM

WRONG CONTACTS CLOSED FOR CLOCKWISE MOTION OF CRANK ARM



ZERO POSITION

Sometimes an input goes into a follow-up control WHEN THE SERVO MOTOR POWER IS SHUT OFF. This results in only one side of the differential being rotated, no response action on the part of the motor being possible.

Without intermittent gearing the crank-arm can be rotated through 360° by a comparatively small input and will turn the crank-arm past the place where the correct contacts are made to touch, and bring it around so that the contacts come together on the opposite side. This will throw the mechanism out of synchronism, since the motor will drive in the wrong direction when the power is turned on.

With intermittent gearing this result can be avoided.

When the crank-arm is in zero position (contacts open) the sector gears are in mesh with the 8-tooth gears as shown. The slightest input causes the spider shaft to turn and rotate the crank-arm a little in either direction, bringing an outer contact against a center contact.

Thus for small signals the contacts move as if the crank-arm were directly driven. Because of this, the follow-up contacts move quickly, giving quick response.

On the other hand, if a signal continues to come in, the disk portion of the intermittent gearing holds the crank-arm stationary with the contacts correctly positioned until the second sector gear has made a complete revolution. This means that the input will turn a considerable number of revolutions before the contacts will be moved again.

The intermittent gearing, therefore, acts like reduction gearing after it has positioned the contacts, and gives the advantage of a large reduction ratio between the differential and the crank-arm.

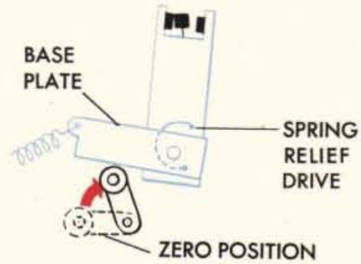
But during the time that the two sector gears are in mesh with the two 8-tooth gears the intermittent gearing is a sensitive direct drive.

is used . . .

In normal operation the motor is energized, and immediately drives its (response) side of the differential at the same time as the input drives. Both input and output move practically simultaneously and the mechanism does not normally get out of synchronism.

When the motor power is shut off, a small manual input will cause the crank-arm to rotate ⅛ turn and close the correct contacts. But the intermittent gearing allows the spider shaft to turn 20 revolutions more before the crank-arm will move again. So it is possible to feed a considerable amount of input into the control and still have the correct contacts remain closed.

When the power is again turned on, the motor will immediately drive in the right direction. The response will rotate the spider back towards zero position, resulting in a correct output corresponding to the input.



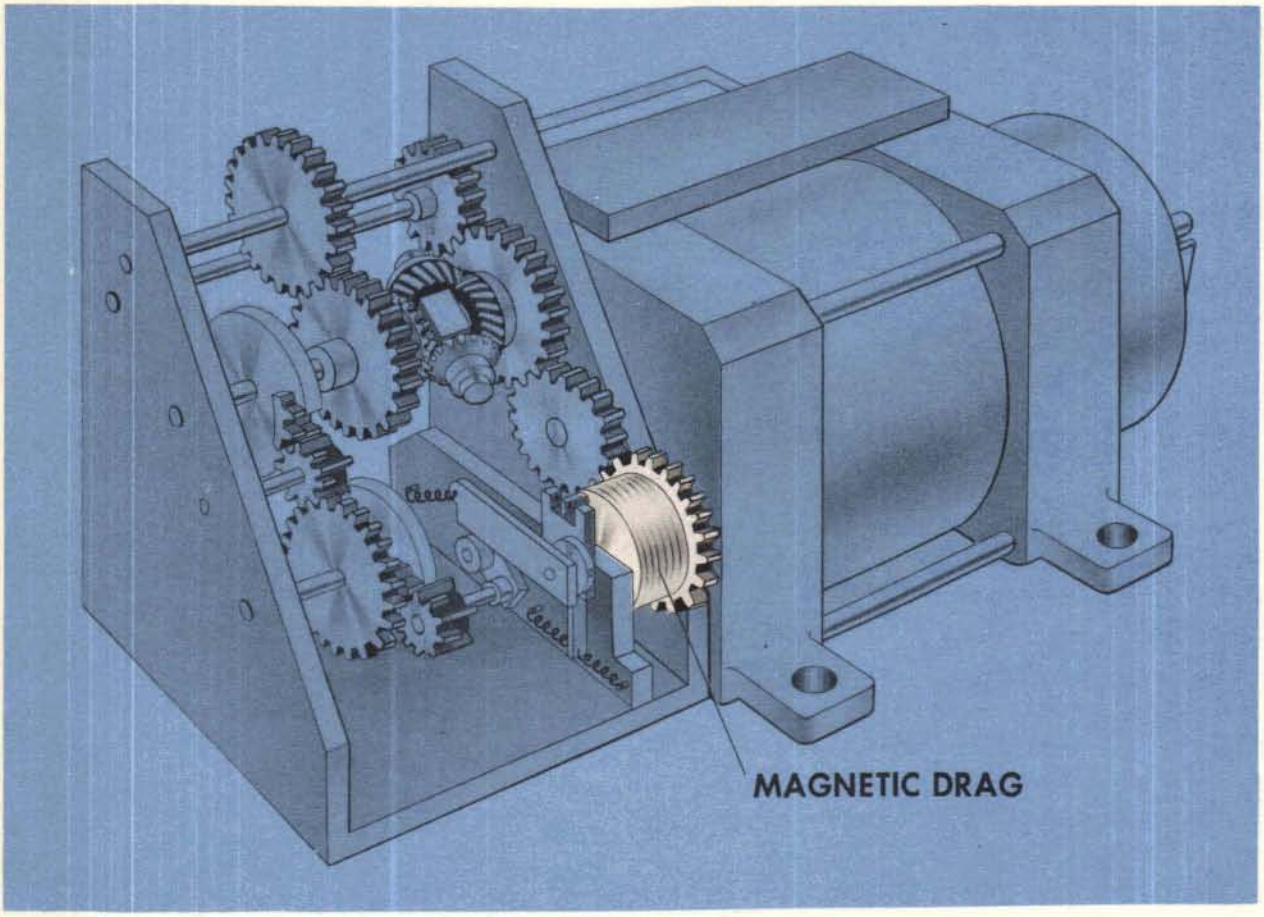
In practice, the range of possible input is increased by using a spring relief drive between the base plate and the outer contacts. This spring drive allows the crank-arm to turn to two positions while the contacts remain closed on the same side.

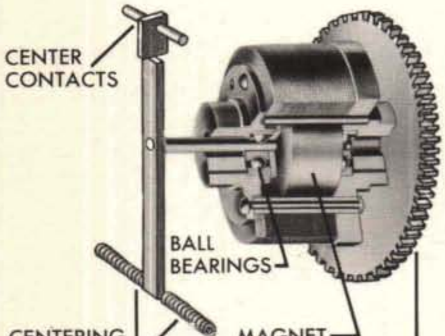
With the same gearing, the spider shaft can now be rotated 40 times, yet the correct contacts will remain closed.

In this manner, synchronism between input and output is maintained throughout a large range of input values.

Any input value coming into a follow-up control when the servo power is off is, in effect, "stored up" in the intermittent gearing until the servo is again energized.

The MAGNETIC DRAG





Up to this point, for the sake of simplicity, the center contact arm has been indicated as fixed to the frame and stationary. In practice, however, the center contact arm is mounted on a shaft which can be rotated, within limits, by a "Magnetic Drag."

This drag consists of an outside frame and an inner magnetized core, to which is fixed the shaft carrying the center contact arm.

The drag is assembled into the follow-up control as indicated above, and the outside frame is geared to the motor rotor shaft

When the servo drives, the outside frame of the drag is rotated. This causes the inner core to be rotated to a certain degree, and the center contact arm is rotated to the same degree, against the pull of the centering springs.

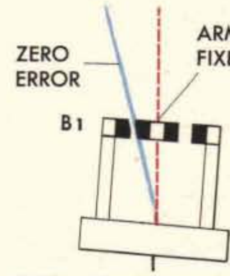
When the motor stops driving, the frame of the drag stops rotating, and the center contact arm is returned to zero position by the centering springs.

Its job in the follow-up

When a signal of a given value goes to a follow-up control, the motor drives until the output equals that value. In doing this, the motor is said to "synchronize to a fixed signal" since the value of the signal remains unchanged.

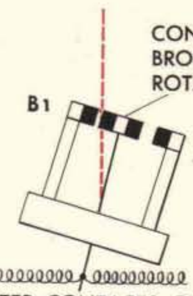
The servo motor, however, is unable to stop suddenly at the point of synchronism, because of the momentum developed by its comparatively heavy rotor and the mechanism which it is driving, which keeps the rotor turning after the power is shut off. The power to the motor must, therefore, be shut off BEFORE the motor reaches the point of synchronism.

The magnetic drag enables this to be done by offsetting the center contact arm, through which current is being supplied, in such a way that the servo response rotates the outer contact away from the center contact before the point of synchronism is reached.



FIXED CENTER CONTACTS. CONTACTS BREAK AT BLUE LINE—POINT OF ZERO ERROR

As this outer contact is rotated away, the *opposite* outer contact is brought up to the center contact. This causes the current in the motor coils to reverse. Reversal of current in the motor coils applies a torque to the servo rotor which tends to prevent the rotor turning in its original direction. Such a torque acts as a brake, rapidly slowing the rotor down, and eventually causing it to reverse its direction of rotation.



CENTER CONTACTS OFFSET. CONTACTS BREAK AT RED LINE—BEFORE THE POINT OF ZERO ERROR

As the rotor reverses, the drag offsets the center contact arm in the opposite direction, and the same process is repeated. Each time the contacts are offset in this manner and torque is applied to the rotor, the speed of the servo is decreased. Action of the magnetic drag, therefore, tends to bring the motor quickly to a standstill.

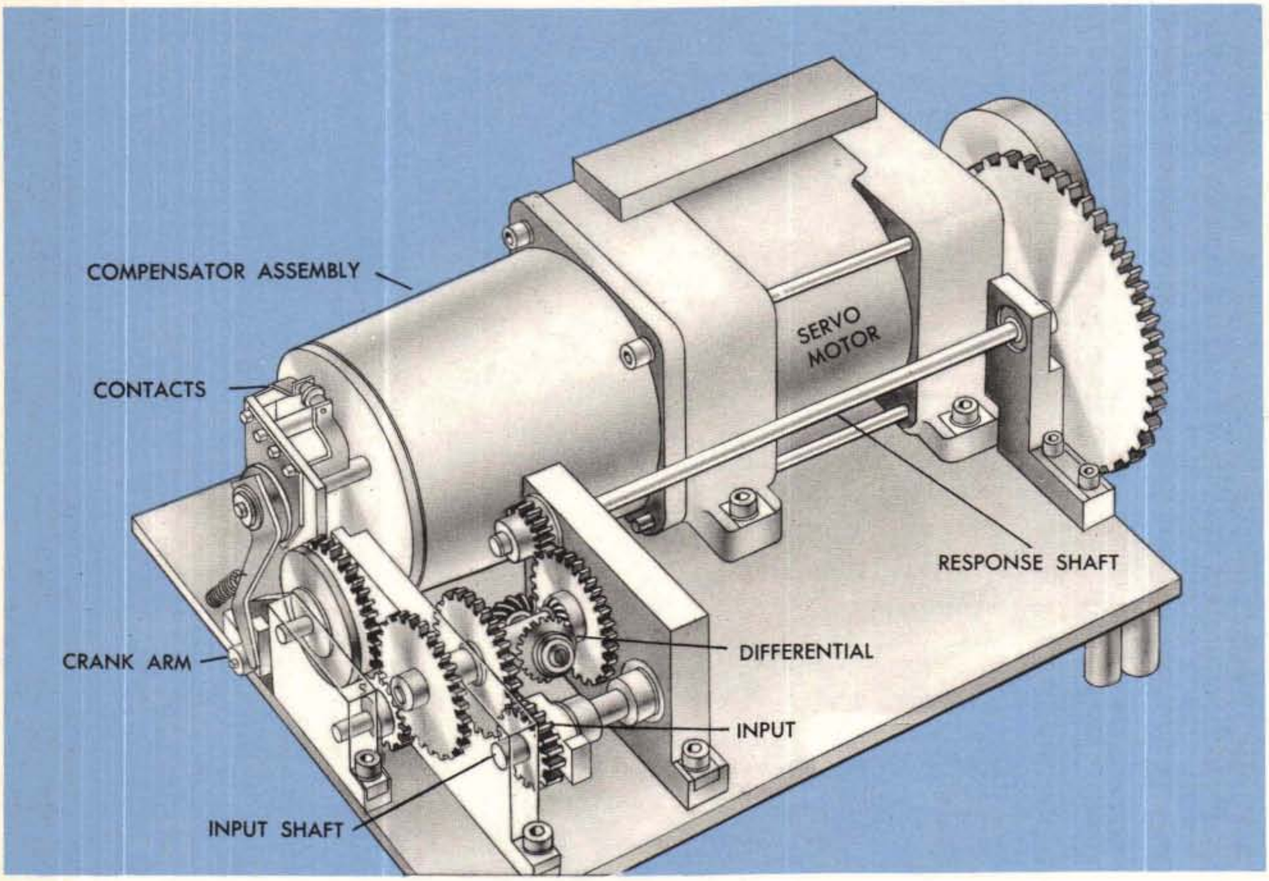
After the motor has been brought to rest at the point of synchronism, and the output, or powered shafting, is positioned exactly in accordance with the fixed value of the input, the drag may come into action in this way:

The load on the powered shafting often causes the servo motor to "drift off" its true position. When this happens the servo response acts through the differential to swing the outer contact arm over in such a way that the motor drives the powered shafting back to its correct position.

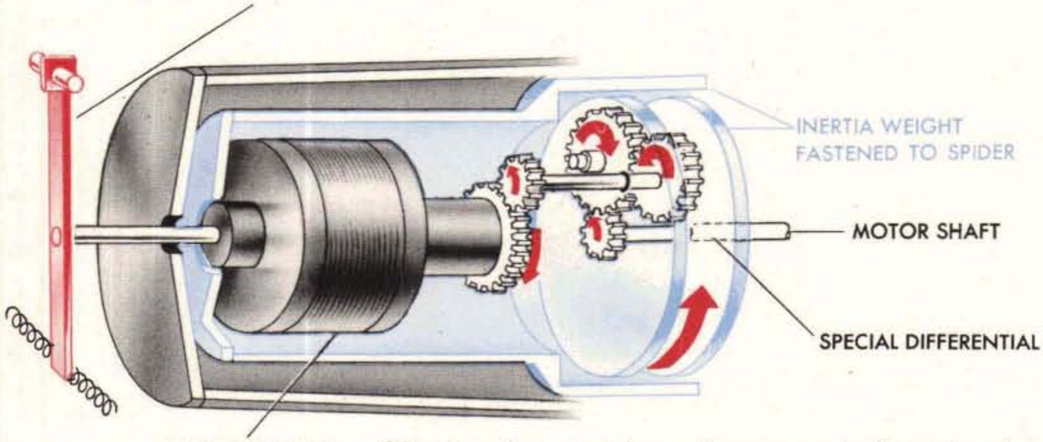
In doing this, the motor again tends to overrun the point of synchronism, and were it not for the action of the drag, a series of oscillations would occur resulting in the servo rotor and the powered shafting swinging back and forth by an amount proportional to the space between the contacts.

Operation of the drag is described in detail in the supplement section titled "Magnetic Drag," page 324.

The COMPENSATED follow-up control



This type of follow-up control is easily recognized by the round grey housing attached to the servo motor.



The housing contains a "compensator" mechanism consisting of a magnetic drag and special type differential equipped with an inertia weight. The operation of the compensator is described in detail on Page 338.

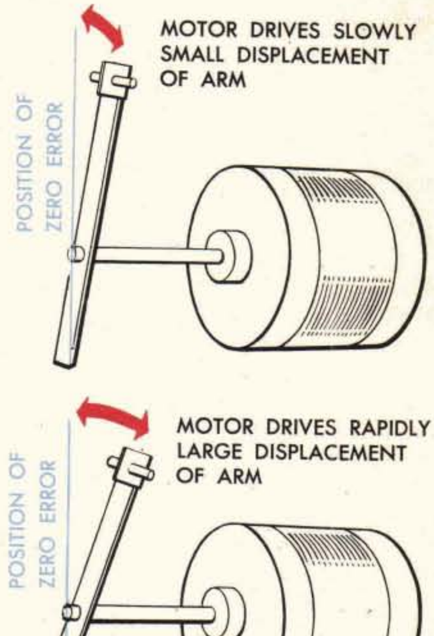
Purpose of the compensator mechanism

It has been shown that the magnetic drag helps to bring the servo motor to rest at the point of synchronism by offsetting the center contact arm.

In doing this job, however, the drag gives the follow-up certain characteristics which cannot be allowed in some applications.

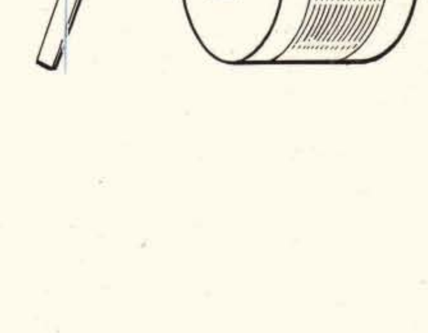
The drag offsets the center contact arm by an amount which is proportional to the speed at which the motor drives. This does not introduce an error as long as the signal is a fixed signal, for the powered shafting is merely positioned in accordance with the value of the fixed input. But when the follow-up has to follow a signal which keeps changing at a constant speed, conditions change. In following such a signal, the motor has to drive at a constant speed to keep the output matched with the input.

As the rotor of the servo turns, it tends to build up speed, and drive too fast. When this happens, the contacts open, for it means that the motor drives past the point of synchronism. When the contacts open, the motor loses speed and the contacts close again. Throughout this operation an outer contact and the center contact make and break the circuit, and the frequent breaking of the circuit prevents the motor from driving too fast.



When a drag is built into a follow-up, the center contact arm is offset and the contacts do not open on the point of zero error. When the contacts do open, the output (or powered shafting) is not on the correct value, although it is moving at the correct speed. The output value will not read exactly the same as the input value at any given instant.

This error can be ignored in some cases but not in all. To eliminate this error the compensator mechanism is included in the follow-up control, and a unit which has such a mechanism is known as a "compensated follow-up."



Operation of the compensated type control

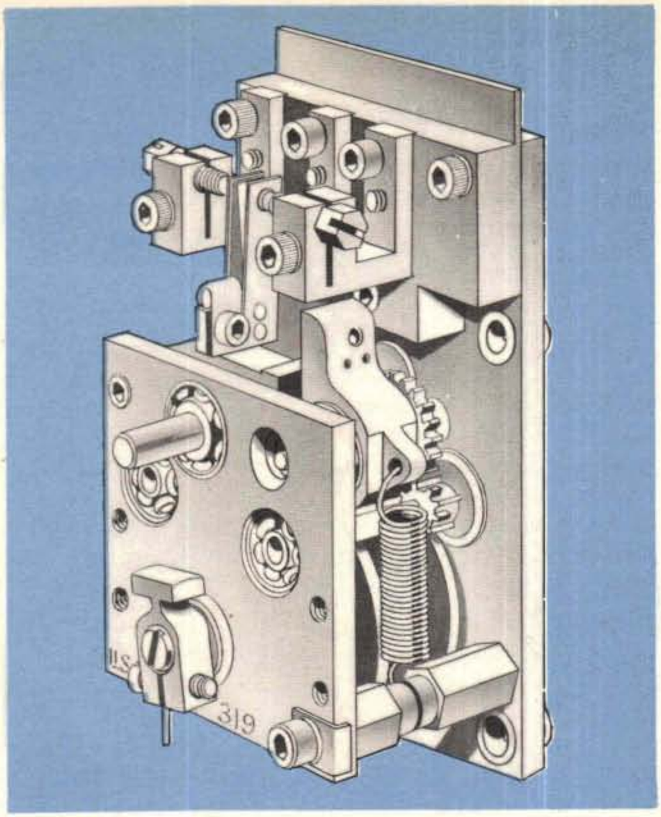
The compensated follow-up is just like the velocity lag type, except that it has a spur gear differential and inertia weight built into it.

For small, quick changes of input, the inertia weight does not move, and the drag acts on the contacts as if only a drag were used. Thus small oscillations are eliminated by the drag.

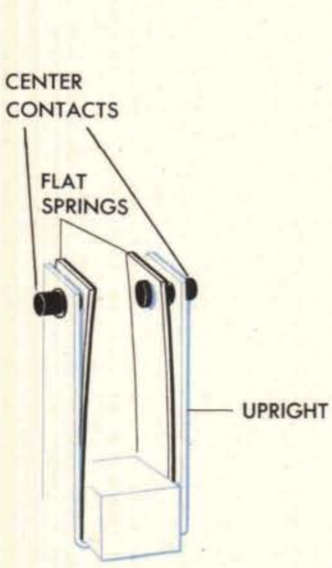
When a signal continues to change at constant speed, however, the inertia weight starts to turn, and gradually picks up speed.

As this happens, the frame of the drag slows down, so that the offset of the center contact arm is reduced gradually to zero—and the arm is returned to its normal position at zero error by the centering springs. This means that there can be no error, or difference, between input and output even though the signal is changing at a constant speed.

The OSCILLATING follow-up control



This type of follow-up is found only in the older types of instruments. It is designed to reduce oscillations of the motor shaft just as the drag and compensator do in the later designs. It consists of a mechanism that causes the center contact to jiggle back and forth between the outer contacts so that contact is made on one side and then on the other very rapidly. When synchronized to a fixed signal the motor gets a "kick" first in one direction and then in the other. These kicks come so fast that the motor shaft only jiggles a little and may be considered stationary. When a change in signal comes into the input, the contacts shift so that the moving center contact makes on one side only and the motor drives in the proper direction. A study of the construction of the parts will make it easier to see just how this works.

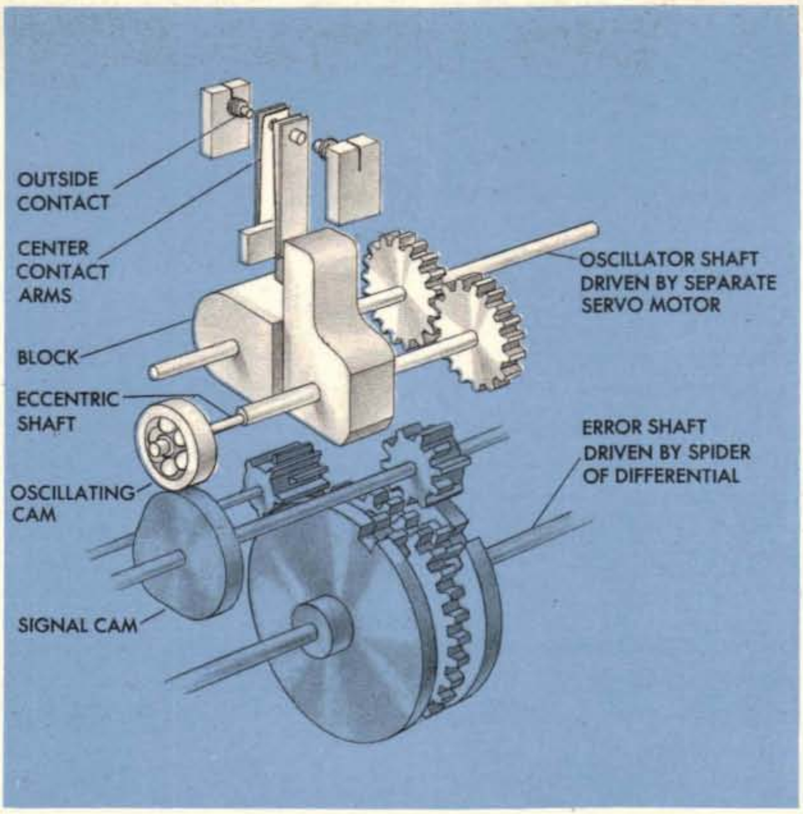


The contact assembly

The outer contacts on this control are stationary, and the center contacts are rotated against them (the reverse procedure to that used by the other type of follow-up controls already described).

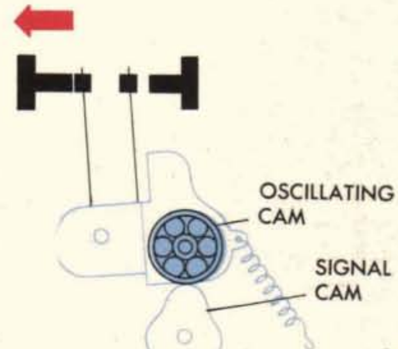
Each center contact is mounted on its individual contact arm, which consists of a stiff upright portion and a flat spring—as shown here. The stiff uprights accurately position the contacts which are mounted on the springs. The springs normally press against the uprights.

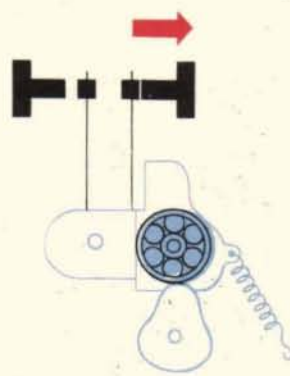
The center contact assembly is mounted on a block, and this block may be moved by two cams. an oscillating cam, and a signal cam.

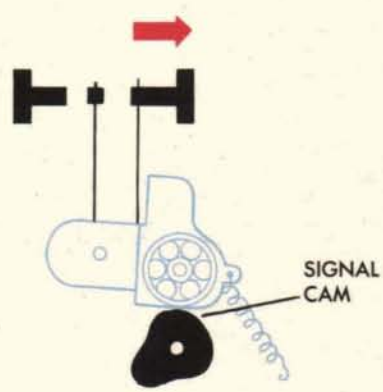


NOTE:

In these diagrams, the shape of the signal cam has been altered to simplify the description of its operation.







The oscillating cam

The oscillating cam is driven around continuously, at constant speed, by a servo motor used especially for this purpose. As it revolves, the cam rocks the center contact assembly block and causes the center contact arms to move a few degrees from side to side. At the point of zero error, when the center contact arms are standing vertical, midway between the outer contacts, the oscillating cam, by rocking the block, can cause the center contacts to tilt over first towards one outer contact and then towards the other. The center contacts are tilted over or "oscillated," *sufficiently to touch one outer contact lightly and then the other in rapid succession.*

The signal cam

Riding against the oscillating cam is the signal cam. This cam is fixed to a shaft which is driven, through intermittent gearing, by the spider of a differential geared to the follow-up servo motor.

Any movement of the differential spider, therefore, causes the signal cam to rotate, and rotation of this cam results in the center contact assembly block being pushed over to one side or the other depending upon the direction of the signal.

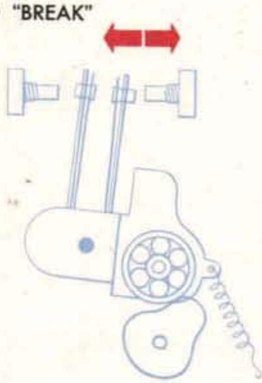
This displaces the center contact arms from their normal, vertical position by a considerable amount, and brings one center contact or the other firmly against an outer contact.

How the OSCILLATING follow-up

It has been shown that the center contacts are moved in two distinctly different ways: (1) they are constantly jiggling back and forth—or vibrating, and (2) they are swung over, when the block on which they are mounted is tilted by the signal cam, against one outer contact or the other.

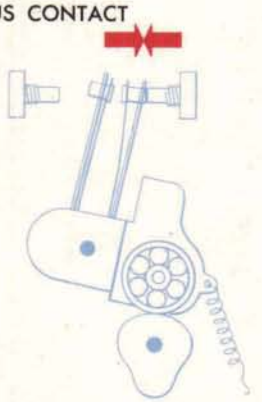
The oscillating cam revolves and causes the center contact arms to oscillate. An incoming signal causes the signal cam to turn and move the center contact assembly toward one outer contact.

SLOWLY CHANGING SIGNAL "MAKE" AND "BREAK"



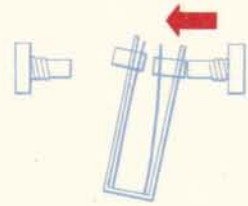
For a fixed signal the center contacts hit both outer contacts equally in rapid succession and the motor shaft merely oscillates a small amount. When the signal value changes slowly, the center contact hits one outer contact longer than the other and the motor, getting a stronger kick in one direction than the other, drives slowly in that direction. For a rapidly changing signal, the center contact continually touches one outer contact and the motor drives continually to follow the signal. In this case the center contact assembly has moved over far enough so that the one contact is held firmly against an outer contact while the spring on which the contact is mounted absorbs the movement caused by the oscillating cam. Consequently there is no "make and break" action and the power supply to the motor is continuous. The motor is continually energized until it builds up speed to follow a rapidly changing signal.

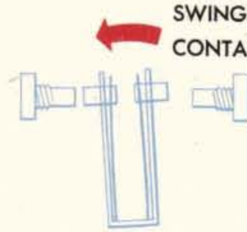
RAPIDLY CHANGING SIGNAL CONTINUOUS CONTACT



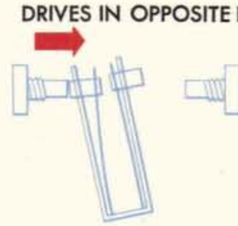
works . . .

The motor always drives the center contact arms back to their normal position, midway between the outer contacts.



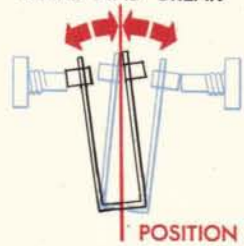


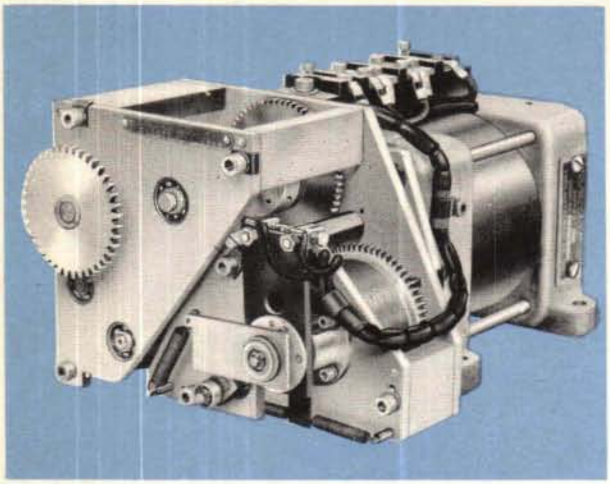
As the motor approaches the point of synchronism, the center contact is no longer held firmly against the outer contact. Instead, it begins to hit the outer contact intermittently and as the error reaches a small value, the center contact begins to hit the opposite outer contact intermittently. The motor then receives a series of "kicks" which tend to stop it before it reaches the point of synchronism.



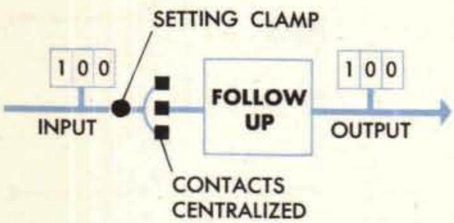
For a fixed signal the arms are centered and the oscillations of the center contact are then sufficient to bridge the gaps between the center and outer contacts, and the servo power supply circuit is closed and broken equally, first on one side and then on the other, in rapid succession. The motor, therefore, is given no chance to build up speed in either direction. Every slight "kick" it receives from the current on one side, is almost immediately neutralized by an equal "kick" from the other side.

The rotor movement becomes so small that it is negligible, and the motor may be considered as standing stationary on the position of zero error.





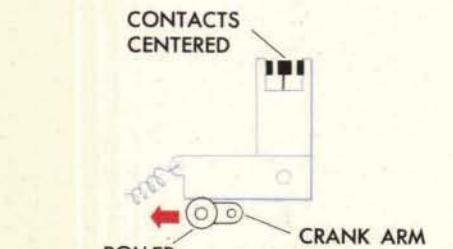
SYNCHRONIZING



The Follow-up is an electromechanical booster that steps up the available mechanical torque for positioning gearing and mechanisms.

The only relationship to be set is the one between the input and the output. For any given setting of the input counter, the contacts should be *centralized* when the output counter agrees with the input counter.

To set the contacts

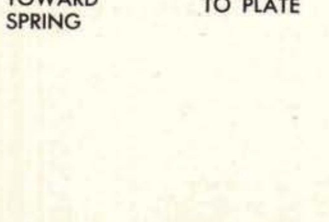


1 Turn the input until the input counter is at zero. Wedge the input.

2 Put the output counter on zero. Wedge it.

3 Centralize the contacts by slipping through the setting clamp. This is called "synchronizing the follow-up." Most follow-ups are synchronized when the following conditions have been satisfied:

- a Contacts centered
- b Roller toward spring
- c Crank-arm parallel to plate

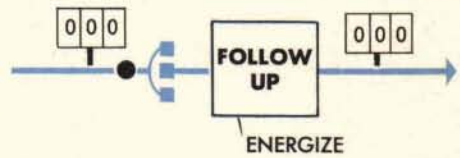


4 Slip-tighten the setting clamp. Remove the output wedge.

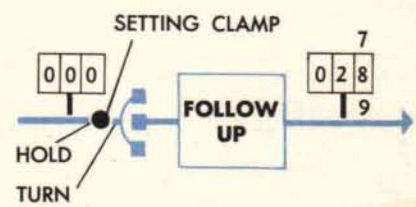
the FOLLOW-UP

5 Energize the follow-up. The output counter should remain in agreement with the input counter, if the contacts are correctly set.

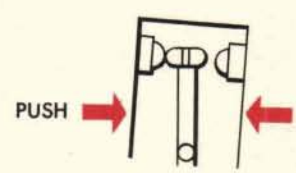
Here these counters are in agreement.



6 Here the counters do not agree, because the contact setting was incorrect.



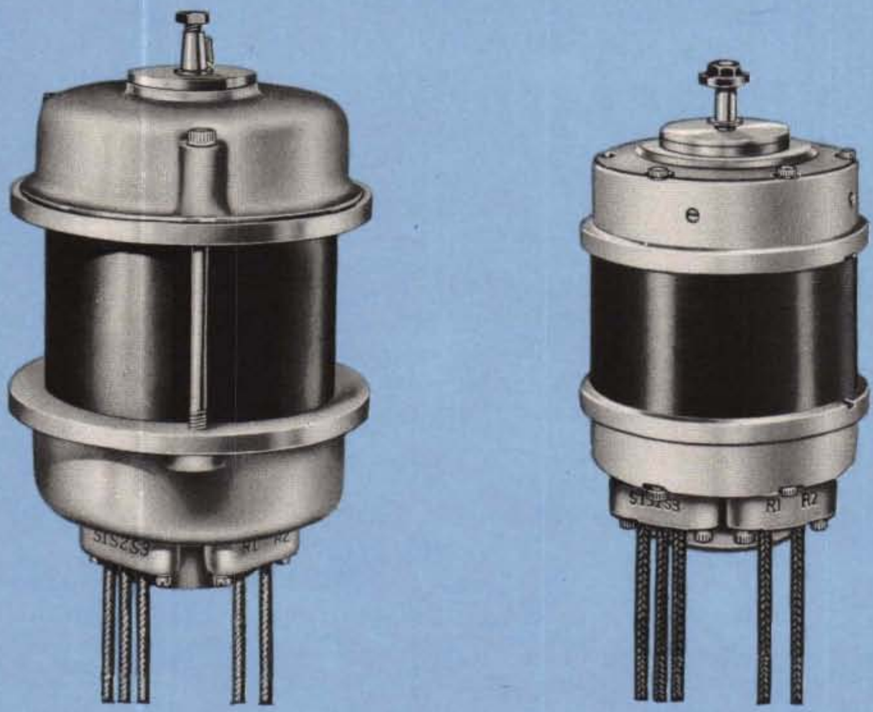
7 To refine the setting, with the power ON, slip through the setting clamp until the readings are the same on both the output and the input counters.



8 Now to check the setting: use a small rod of non-conductive material to push the follow-up contacts first in one direction, and then in the other. The motor should return the output counter to the same reading each time.

9 Tighten the setting clamp after the counter readings are matched.

SYNCHROS



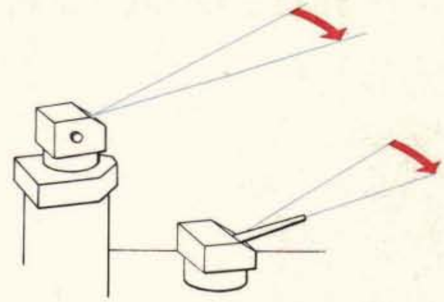
SYNCHRO GENERATOR
(TRANSMITTER)

SYNCHRO MOTOR
(RECEIVER)

Synchro generators and synchro motors are used at many points in fire control systems to transmit information electrically from one place to another. The generator, or transmitter, sends out signals and the motor, or receiver, receives them.

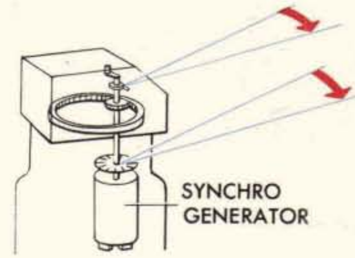
Synchros are connected in such a way that any amount of rotation of the generator rotor will cause the rotor of the motor to turn the same amount.

The receiver either indicates the value of the signal by turning a dial, or controls the action of a servo motor, by means of which the value is used to position other mechanisms in the fire control system.

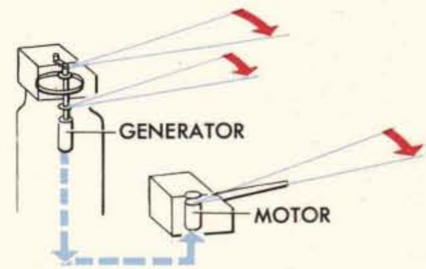


Here's the way they work

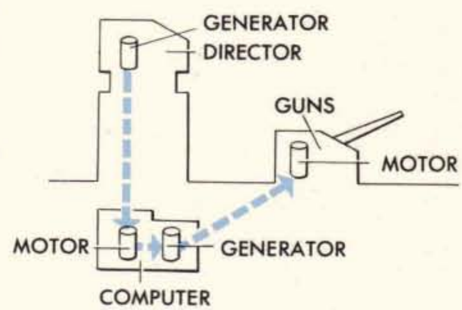
Suppose that it is desired to keep two pieces of equipment, a director and a gun for instance, always pointing in the same direction. Assume that the control is in the director.



When the director is turned, the rotor of a synchro generator (transmitter) geared to the director is turned. A dial may be geared to the synchro generator shaft to indicate the amount the director has turned, but this has nothing to do with transmitting a signal. An electrical signal, representing the amount the transmitter rotor has turned, is transmitted over wires to a synchro motor (receiver) located, in this case, at the gun. This signal causes the rotor of the synchro motor to turn, or attempt to turn the same amount as the generator rotor has been turned.



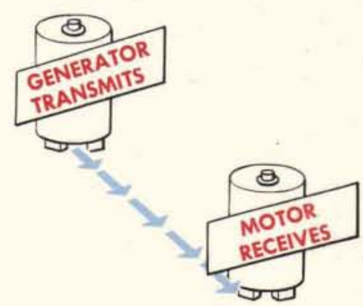
If the synchro motor is connected to a power drive (through a servo system) it will control the drive, and thus cause the gun to turn the same amount as the director is turned.



In most cases a synchro generator in the director transmits signals to a synchro motor in the computer, causing certain computer mechanisms to operate.

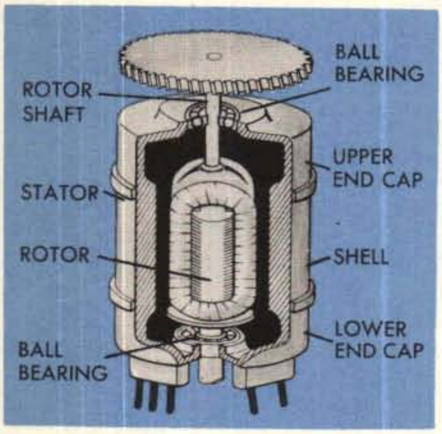
The computer mechanism, in turn, operates another synchro generator and this second generator then sends out signals to a synchro motor in the gun mount.

Synchros team up for many jobs



Data concerning Elevation, Range, Ship Course, and so on are all handled by synchros working in pairs—teams of generator and motor, or two generators and two motors.

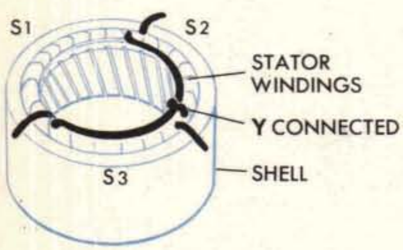
The GENERATOR or TRANSMITTER



A synchro generator, or transmitter, consists of two major parts: a stator and a rotor.

The stator consists of an upper end cap, a "shell"—on the inner side of which are slots containing the stator windings—and a lower end cap.

Ball bearings on the rotor shaft fit into the upper and lower end caps.



How the STATOR is wired

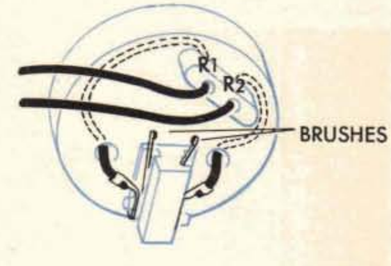
Inside the stator shell are three windings or coils.

By taking a lead wire from one end of each winding, and joining these leads together, a common connection is made.

The coils are now said to be *Y* connected, as the three leads are the arms of a letter *Y*.

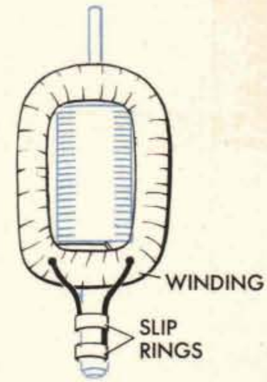
The other end of each winding has a lead wire soldered to it. These lead wires are also labeled *S1*, *S2*, and *S3*, and they pass through a guide block in the lower cap.

How the ROTOR is wired



Two carbon composition brushes are assembled inside the lower cap and to these are connected leads labeled *R1* and *R2*.

The rotor has a winding connected to slip rings on its shaft.



When the rotor is assembled in the stator, the two carbon brushes, just mentioned, bear against these slip rings.

In this way, current can be supplied through leads *R1* and *R2* to the rotor winding and the rotor will still be free to turn.

THE BRUSHES BEAR AGAINST THE SLIP RINGS

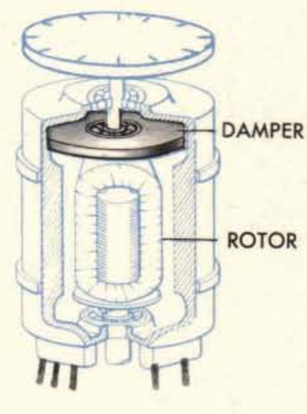
The important parts of the synchro generator are three stator or field coils, with one end of each brought to an outside terminal, and a rotor which can be energized by connecting its two leads directly to an outside source of supply.

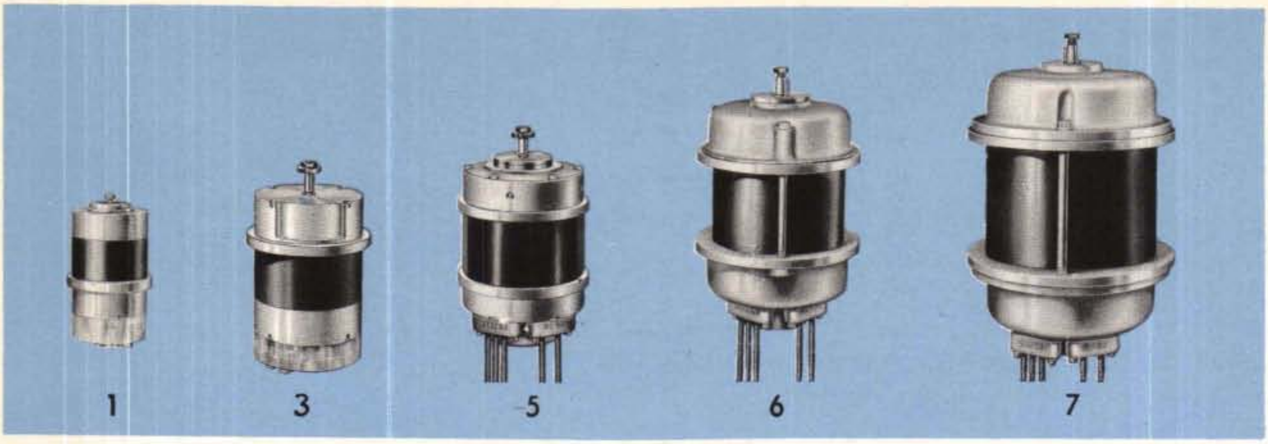
The MOTOR or RECEIVER

The synchro motor, or receiver, is like the synchro generator in construction and electrical operation.

The generator rotor is turned by gearing, and stops as soon as the input ceases. But the rotor of a receiver is turned by electrical signals and, therefore, it may oscillate before coming to rest. Also, certain signals may cause the rotor of a receiver to spin.

To prevent spin, each motor is equipped with a damper. Generators do not have a damper.





There are several sizes and types of synchros

SIZES of synchros are designated by numbers

Synchro Generators in general use are sizes 1, 5, 6, and 7.

Synchro Motors in general use are sizes 1 and 5.

TYPES of synchros are designated by letters

Generators are type *G*, differential generators are type *DG*, special generators are type *SG*, and special differential generators are type *SDG*.

Ball-bearing motors are type *B*, flange-mounted motors are type *F*, special flange-mounted motors are type *SF*, differential motors are type *D*, and nozzle-mounted motors are type *N*.

Control transformers are type *CT* and high-speed control transformers are type *HCT*.

The size of a motor or generator used depends upon the amount of work to be done.

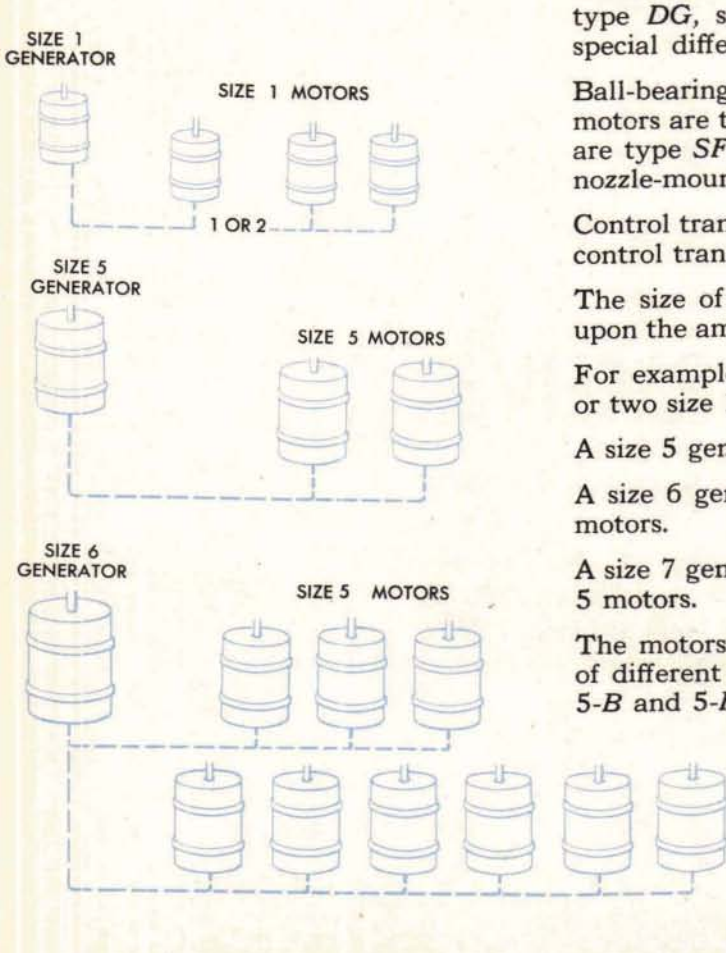
For example, a size 1 generator can control one or two size 1 motors.

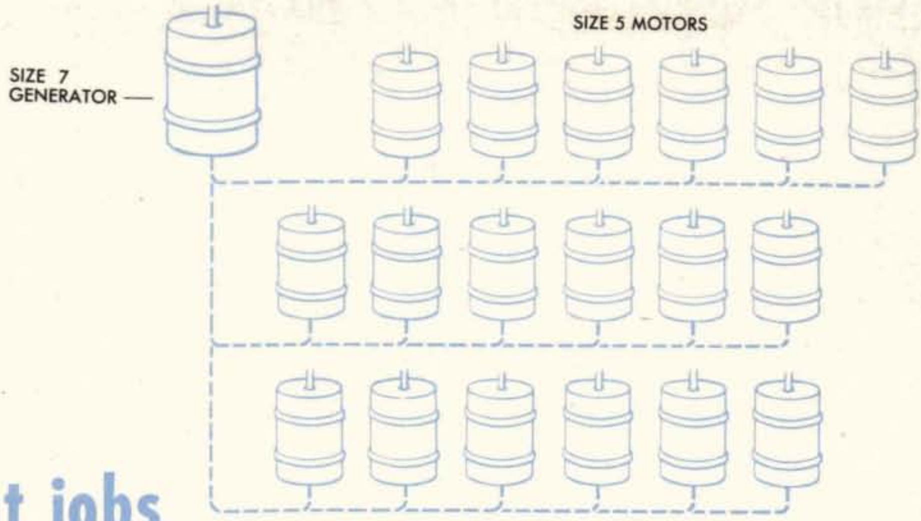
A size 5 generator can control two size 5 motors.

A size 6 generator can control up to nine size 5 motors.

A size 7 generator can control up to eighteen size 5 motors.

The motors controlled by one generator may be of different types. The most commonly used are 5-*B* and 5-*F* motors.



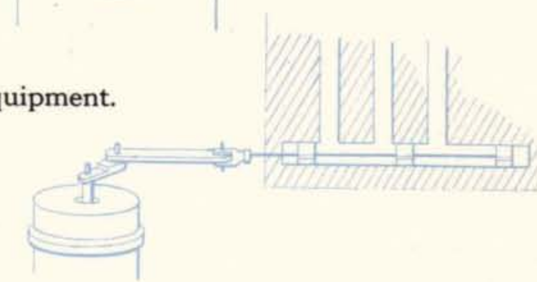


for different jobs

A synchro motor can be used directly to position a dial.

It can do other light work. For example, it can be used to close contacts which control the action of a servo motor.

It can operate pilot valves that control hydraulic equipment.



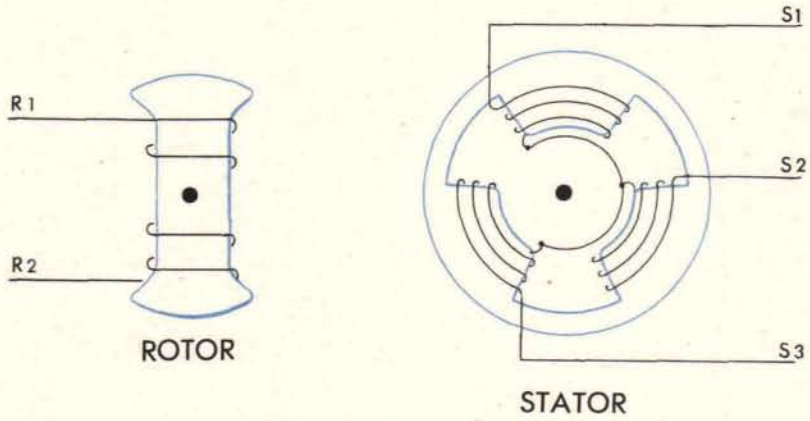
Since synchro motors can be used to operate many types of equipment, the synchro system of transmission provides a versatile form of remote control.

ELECTRICAL OPERATION

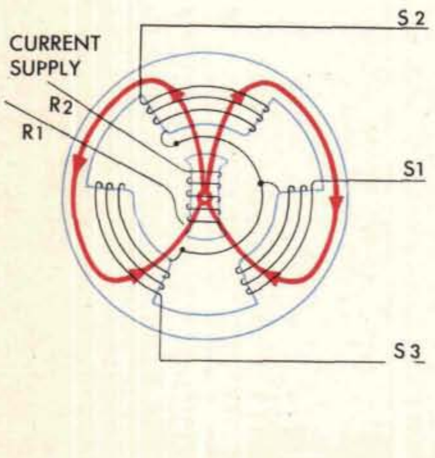
The synchro generator and synchro motor are identical so far as their electrical features are concerned.

The electrical operation of either a generator or a motor can be followed by examining the wiring of a rotor and stator, and describing what happens when current is supplied to the coils.

Here are a rotor and a stator shown schematically:



How voltage is induced



When current is passed through the rotor winding, the rotor sets up a changing magnetic field.

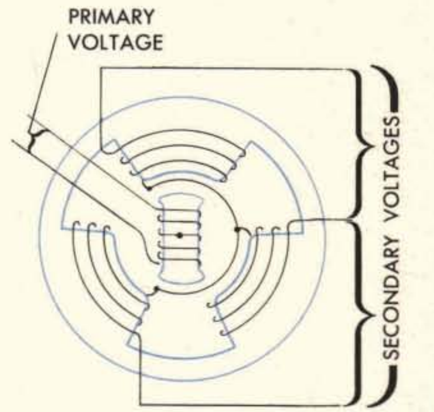
The lines of force in this field cut through the stator coils, and an electrical pressure is induced in each coil.

The electrical pressure is measured in volts. So it can be said that a voltage is induced in each coil.

All the voltages given in this description are the effective voltages. As will be seen later the effective voltage may consist of both a plus and a minus voltage. For example, if a + 52 voltage, induced in one coil, is combined with a −26 voltage, induced in another coil, the connections are such that the effective voltage will be 78 volts. The effective voltage can be read by connecting a voltmeter across any two of the *S* leads.

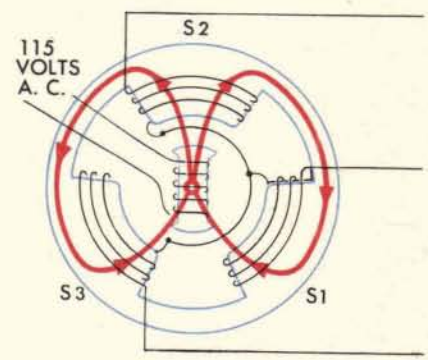
of the SYNCHRO UNIT

The synchro acts like a transformer

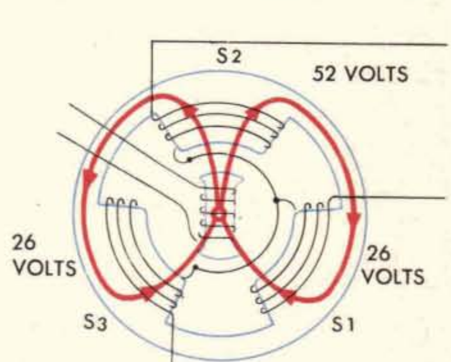


If the voltage applied to the rotor winding from the outside source of supply is called the "primary" voltage, and the voltage induced in the stator coils the "secondary" voltage, it will be seen that synchro operation is based upon the transformer principle.

The current used to energize the rotor is single phase, 60 cycle, 115-volt, A.C. In following what happens in the synchro windings, remember that this current keeps reversing—changing polarity—*120 times each second.* Any description of an electrical condition in the synchro tells what is happening only during a given instant.



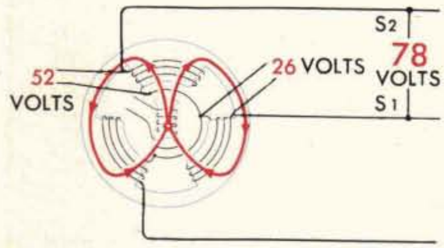
When 115 volts A.C. is supplied to the rotor coils, with the rotor in this position, the lines of force in the magnetic field set up by the rotor will take the directions shown by the arrows. Both sides of the field cut the *S2* winding of the stator, while one side of the field cuts the *S3* winding, and the other side cuts the *S1* winding.



If the induced voltages in the stator windings are measured with a voltmeter, it will be found that 26 volts are induced in the *S3* winding, which is cut by only one side of the magnetic field. A pressure of 26 volts is also induced in the *S1* winding, which too is cut by only one side of the magnetic field. And 52 volts are induced in the *S2* winding, because both sides of the magnetic field cut this winding.

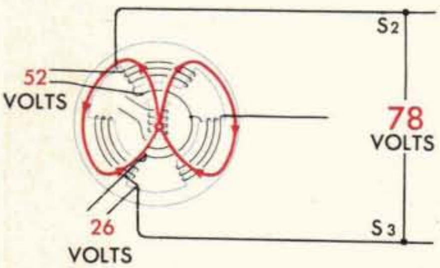
Combining COIL

When one end of the ROTOR is OPPOSITE the S_2 coil

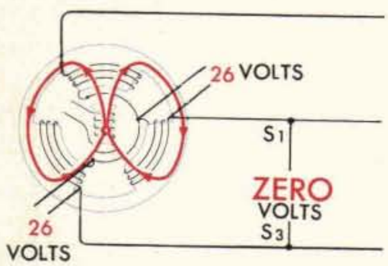


The coils of the stator are Y-connected, so the 52 volts from the *S2* winding add to the 26 volts from the *S1* winding to give a total of 78 volts across the *S2* and *S1* leads.

In addition to indicating the paths of the rotor field the arrows on the diagrams indicate the phase relationship of the three Y connected stator coils. When the arrows passing through a stator coil are going away from the rotor, the coil voltage is in phase with the *R1-R2* voltage. When the arrows through a coil are going toward the rotor the coil voltage is out of phase with the *R1-R2* voltage. When combining the voltages of two coils that are both in phase, or both out of phase, the connections are such that the effective voltage is the *difference* between their two voltages. When combining the voltages of a coil in phase and a coil out of phase, the effective voltage is the *sum* of their two voltages.

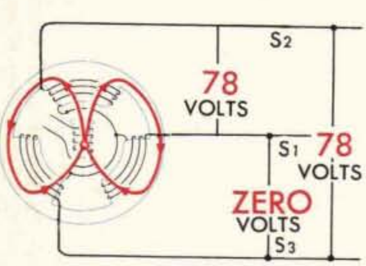


Similarly, the 52 volts from the *S2* winding add to the 26 volts from the *S3* winding to give a total of 78 volts across the *S2* and *S3* leads.



But the 26 volts from the *S1* winding oppose the 26 volts from the *S3* winding, because both coils are out of phase.

This results in zero volts across the *S1* and *S3* leads.



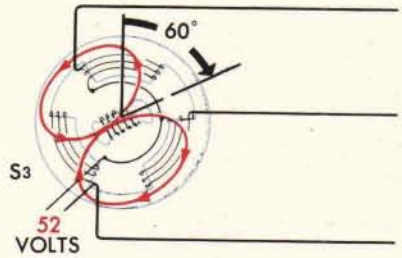
This position of the rotor (when the voltage across *S1* and *S3* is zero and the voltage across *S2* and *S3* is in phase with the *R1-R2* voltage) is known as the electrical zero position. A synchro in this position is said to be on "electrical zero."

It is important to remember the position of a synchro on electrical zero because it is used in installing, testing, and setting.

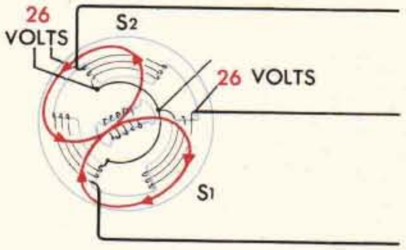
VOLTAGES

When one end of the ROTOR is BETWEEN the S_1 and S_2 coils

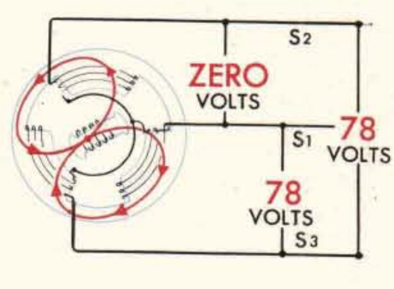
Suppose the rotor is now turned through 60°. The 52 volts are now induced in the *S3* winding, because both sides of the magnetic field are cutting this winding.



Then 26 volts are induced in the *S2* and 26 volts in the *S1* winding.



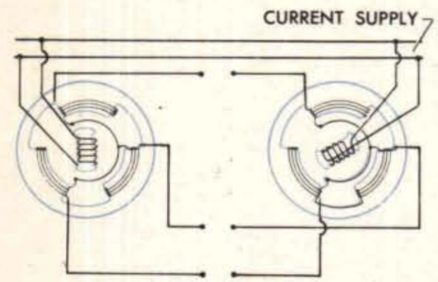
This shows that a change in rotor position changes the voltages of the stator coils.



When the rotor of a synchro *motor* is energized, voltages are induced in the stator coils in just the same way, since, electrically, a synchro motor is constructed on the same principle as a synchro generator.

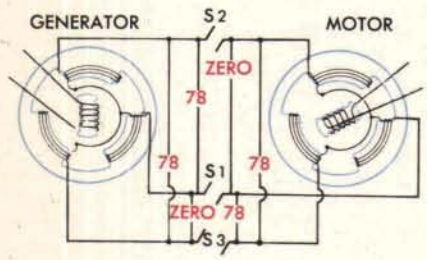
SYNCHRO TEAMWORK

The explanation of the way voltages are induced in the stator coils of both generators and motors, by action of their rotor fields, makes it fairly easy to understand how the motor follows a signal from the generator, when the two units are connected together to work as a team.



Connecting the ROTORS to the current supply

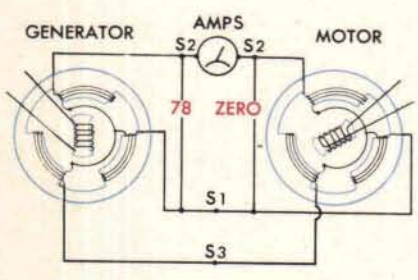
Suppose a generator and a motor are to be connected, and the rotors of each are first connected to the outside source of current supply.



If the rotor of the generator is in zero position, and the rotor of the motor is 60° from zero, the generator and motor will look like this schematically, the stators not yet having been connected.

Voltages across the **GENERATOR** leads will register as 78 volts across *S1* and *S2*, 78 volts across *S2* and *S3*, and zero volts across *S1* and *S3*. Voltages across the **MOTOR** leads will register as zero across *S1* and *S2*, 78 volts across *S2* and *S3* and 78 volts across *S1* and *S3*.

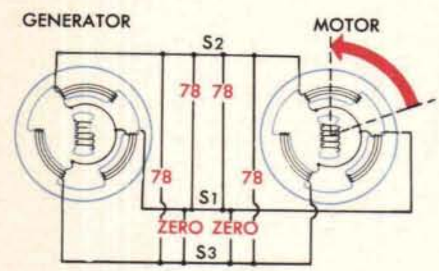
Connecting the STATORS



Now the stators are connected. The *S1* lead of the generator to the *S1* lead of the motor, the *S2* to the *S2* and the *S3* to the *S3*.

Whenever there is a difference of potential between two points which are joined by an electrical conductor, a current will flow.

So with 78 volts registered across one set of leads, and zero volts across another, as in the case of the *S1* and *S2* leads, current will flow when the leads are joined together.



Such a current flow in the stator windings produces a torque, or turning force, on the rotors of both the motor and the generator.

The rotor of the generator is held stationary; it can only turn when the gearing used to transmit signals is turned. But the rotor of the motor is free to move.

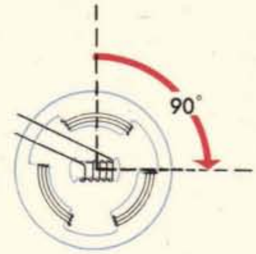
The rotor of the motor, therefore, turns until the voltages from the motor equal those from the generator.

This means that the rotor of the motor turns until both rotors are aligned, for, in this position, the voltages generated in the motor windings are equal to those generated in the generator windings.

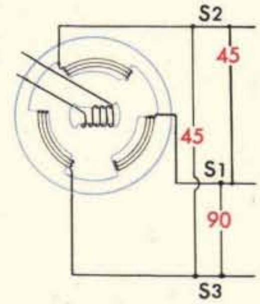
It also means that no more current flows and, consequently, *the torque falls to zero.* The two rotors will remain aligned until the voltages are disturbed again.

Here's another example

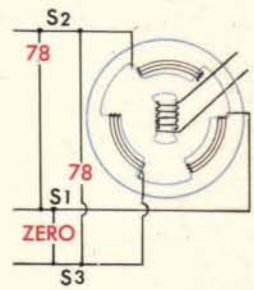
Suppose the rotor of the generator is now turned through 90°.



Voltages measured across the **GENERATOR** leads will read 45, 45, and 90.



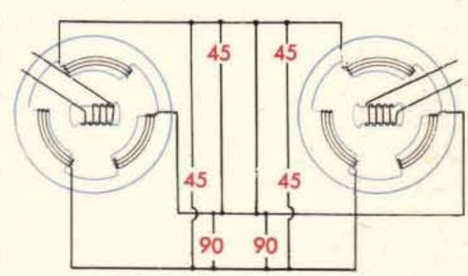
But remember that the voltages across the **MOTOR** leads, with the rotor in zero position, read 78, 78, and zero.



This difference in voltages, between the motor and generator leads, causes current to flow, and the rotor of the motor turns until the voltages across the motor leads equal the voltages across the generator leads.

When there is no difference in the voltages, the two rotors will again be aligned.

Also, voltages being equalized, there is no further current flow. The torque exerted on the rotors is zero, and the rotors will remain aligned until the voltages are again disturbed.



In synchro transmission, any movement of the rotor in the synchro generator produces a corresponding movement of the rotor in the synchro motor. The position of the rotor of a synchro receiver always conforms to the positions of the rotor in a synchro transmitter.

SYNCHRO DIFFERENTIAL GENERATORS

SYNCHRO
DIFFERENTIAL
GENERATOR

SYNCHRO
DIFFERENTIAL
MOTOR

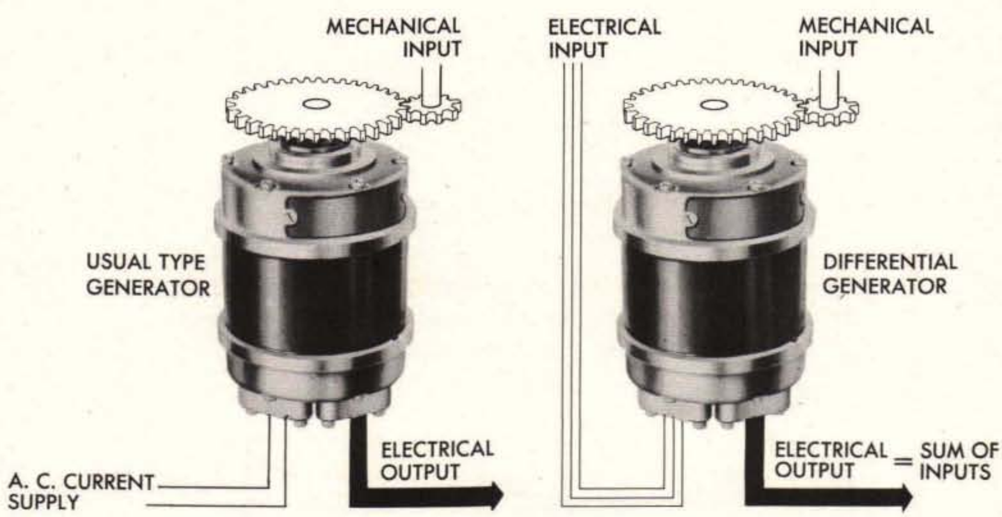
DIFFERENTIAL GENERATOR

The difference between a synchro *differential* generator and the usual type of synchro generator is this:

The usual type of generator transmits the value of a signal which is cranked in mechanically.

The differential type generator transmits the sum of two values. One is cranked in mechanically; the other is fed in electrically from a regular generator. Mechanical and electrical inputs may be put in separately or simultaneously.

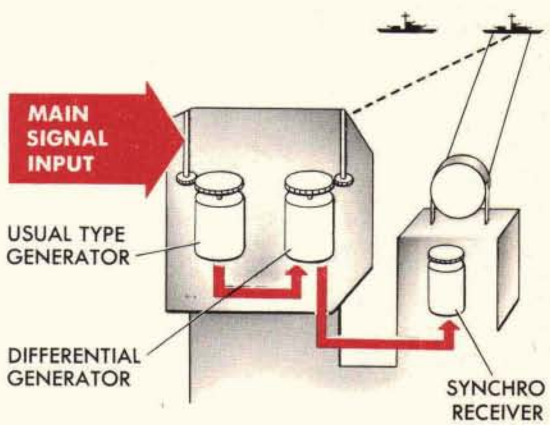
The differential generator obtains inputs from two separate sources and transmits the sum of these inputs to a synchro motor, which positions whatever mechanism is being handled.



and MOTORS

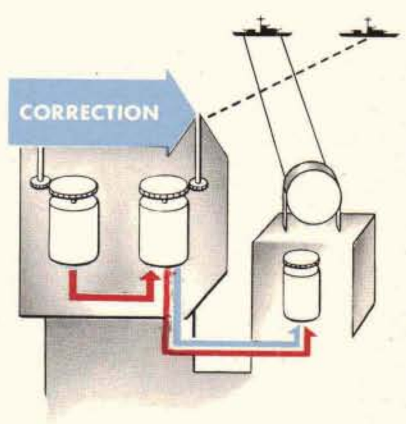
The synchro differential in action

Suppose a searchlight is synchronized so that it trains with a director. The synchro hook-up can be arranged as shown here. A usual type generator, geared to the director, transmits a signal to a differential generator (here shown as located in the director).



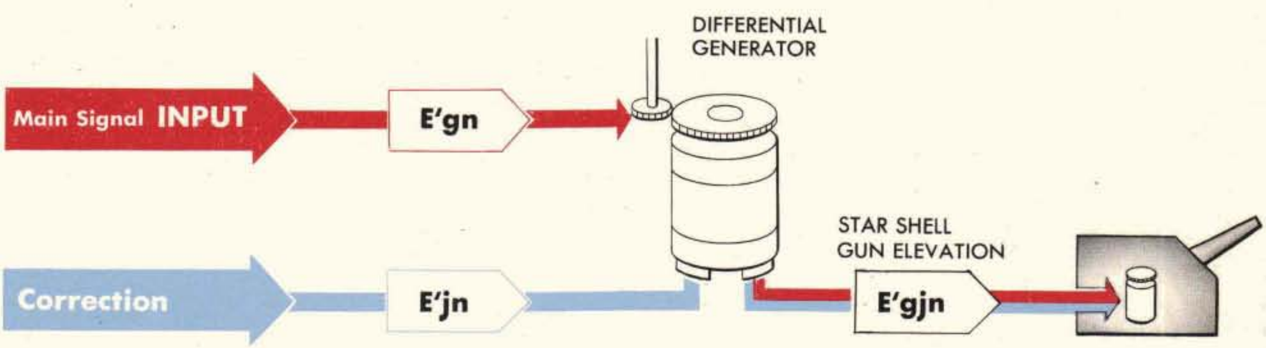
If no other input is set into the differential generator, the signal passes on unchanged to the synchro receiver controlling the mechanism which controls the searchlight, and the searchlight is trained, exactly as the director trains. The searchlight, therefore, points to the exact spot on which the crosswires of the pointer's and trainer's telescopes are registered. (Parallax has been ignored.)

If a value is now set into the differential generator by hand, the total value of the signal transmitted to the synchro receiver changes, and the position of the searchlight changes, even though the director remains stationary.



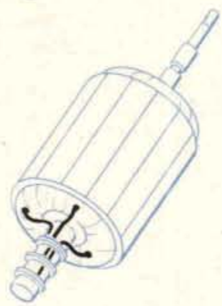
In this way, the searchlight can be trained independently of the director when desired. Here, for instance, the searchlight has been trained away from the ship on which the director is trained to a second ship, which is following.

Another example of the use of a differential generator is found in star shell fire. The main gun elevation signal is computed and cranked into a differential generator, mechanically. A correction for elevation—or elevation spot—is fed in electrically. The sum of these two values forms the output signal which is final gun elevation order.



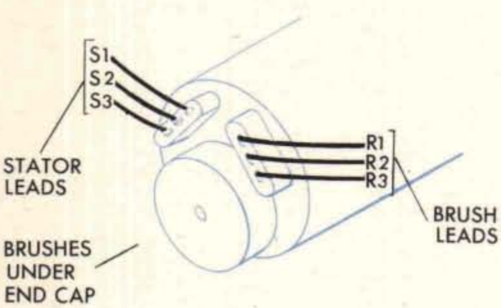
The 3-PIECE SYNCHRO TEAM

The differential generator looks like the usual type of synchro generator. Actually, the stator is the same. The difference lies in the rotor.

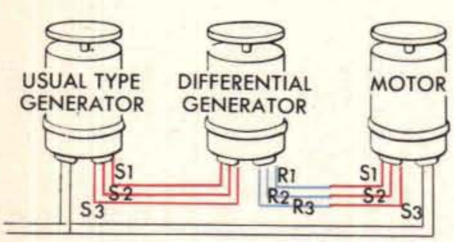


The rotor has three windings on a slotted core. The windings are Y-connected.

One end of each winding is connected to a slip ring on the rotor shaft.



Three brushes, assembled in the lower end cap of the generator, bear against the slip rings, and the leads connected to these brushes are labeled *R1, R2, R3*.



The 3-piece synchro team, which is formed with the differential generator, is wired as indicated here. Note that the differential generator is not connected to the 115-volt A.C. supply.

The *S1, S2,* and *S3* leads of the usual type generator, which is now called merely the "generator," for simplicity, are connected to the stator of the differential generator.

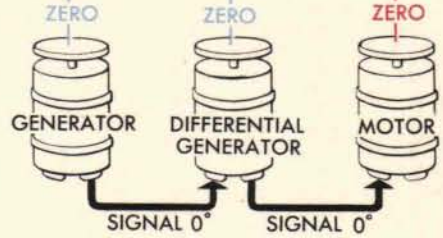
And the *R1, R2,* and *R3* leads, from the rotor of the differential generator, are connected to the three stator leads of the motor.

How it works

Example 1

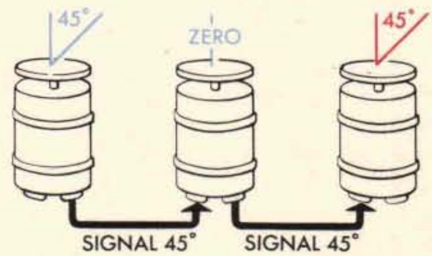
Suppose the generator is set on zero, and the differential generator is also set on zero.

The motor dial registers zero, because no signal is being transmitted.

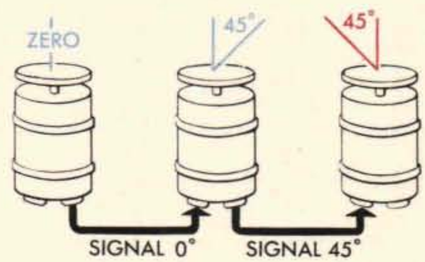


Suppose the rotor of the generator is turned 45° clockwise, while the differential rotor is held stationary on zero by means of the input gearing.

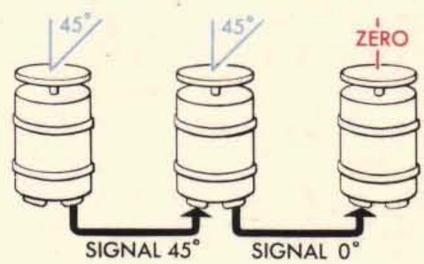
The rotor of the motor turns 45° clockwise because the signal has been transmitted through the differential generator from one end of the hook-up to the other without being changed at any place along the route.



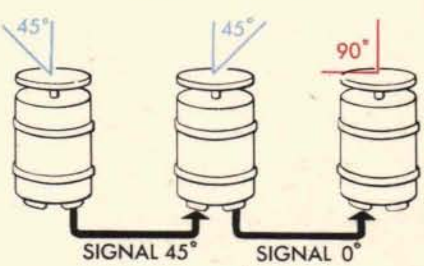
Now if the *generator* rotor is held at zero, and the *differential generator* rotor is turned 45° *clockwise,* the rotor of the motor will turn 45° *counterclockwise.*



Suppose now that the rotor of the generator is turned 45° clockwise. The rotor of the motor will return to zero, because the 45° signal from the generator now cancels the signal from the differential generator.



If, however, the rotor of the generator is turned 45° counterclockwise, while the rotor of the differential is held at 45° clockwise, the rotor of the motor will turn 90° counterclockwise. This is because the signal from the generator is now added to the signal from the differential generator.



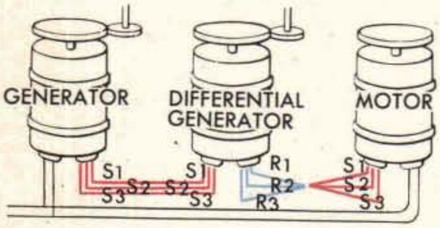
The motor will be positioned by:

1 The sum of the two inputs if they are in opposite directions.

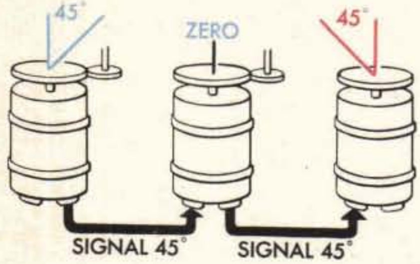
2 The difference between the two inputs if they are in the same direction.

More about how it works

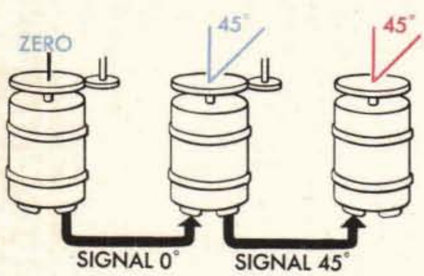
Example 2



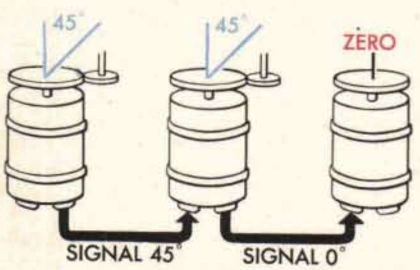
When the *R1, R2,* and *R3* leads from the rotor of the differential generator are crossed, so that the *R1* lead is connected to the *S3* stator lead of the motor, and *R3* to the *S1* stator lead, as shown here, then results will be obtained as follows:



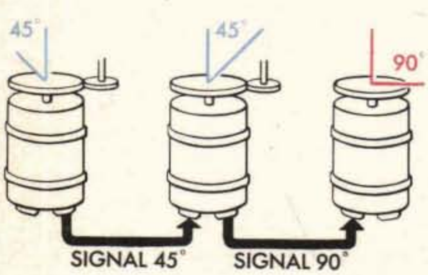
If the rotor of the generator is turned 45° clockwise, while the differential rotor is held at zero by input gearing, then the rotor of the motor turns 45° counterclockwise.



If the generator rotor is held on zero, and the differential generator rotor turned 45° clockwise, the rotor of the motor will turn 45° clockwise.



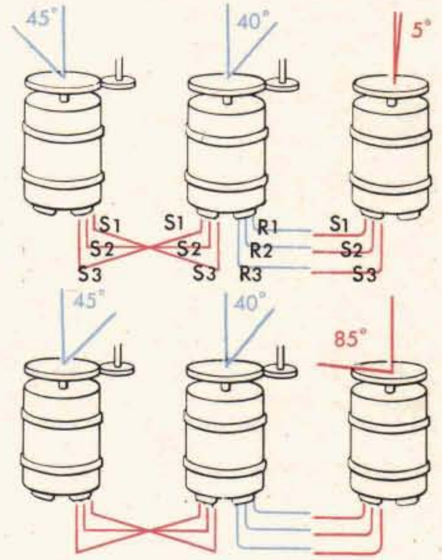
Suppose now that the rotor of the generator is turned 45° clockwise. The rotor of the motor will turn to zero—as the signal from the generator cancels the signal from the differential generator.



If, however, the rotor of the generator is turned 45° counterclockwise, while the differential is held at 45° clockwise, the rotor of the motor will turn 90° clockwise.

This hook-up results in the rotor of the motor turning in the opposite directions to those shown in the previous example.

Example 3

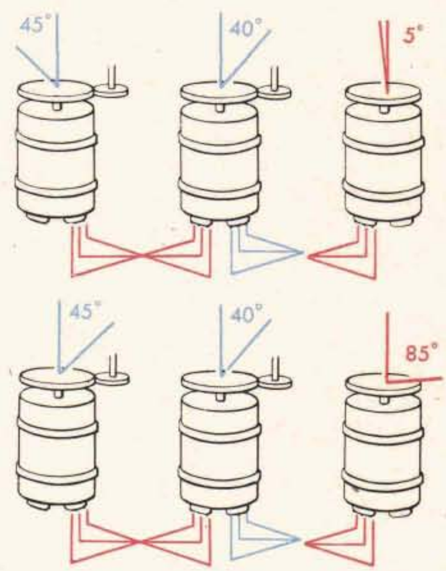


When the stator leads of the generator and the stator leads of the differential generator are crossed, as indicated here, the rotor of the motor turns in such a direction that the reading on the motor dial is the sum of the generator and differential generator readings in the opposite direction to the generator.

For example, if the rotor of the generator is turned 45° counterclockwise, and the rotor of the differential 40° clockwise, the rotor of the motor will turn 5° clockwise.

And if the rotor of the generator is turned 45° clockwise while the rotor of the differential is held at 40° clockwise, the rotor of the motor will turn 85° counterclockwise.

Example 4



When both sets of leads are crossed, as shown here, the rotor of the motor turns in such a direction that the reading on the motor dial represents the sum of the generator and differential generator readings in the same direction as the generator.

For example, if the generator rotor is turned 45° counterclockwise, and the differential rotor is turned 40° clockwise, the rotor of the motor will turn 5° counterclockwise.

And if the rotor of the generator is turned 45° clockwise, while the differential is held 40° clockwise, the rotor of the motor will turn 85° clockwise.

SUMMARY:

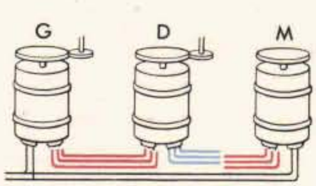
The results of these various hook-ups can be summarized in four equations. In these equations

G = Generator rotor angle

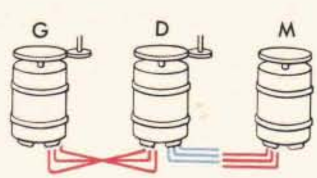
D = Differential generator rotor angle

M = Motor rotor angle

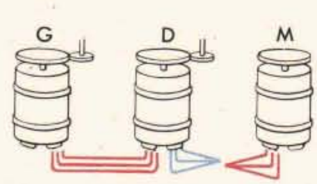
Clockwise rotation is represented as *plus* and counterclockwise rotation as *minus.*



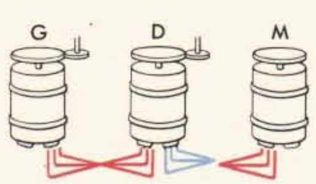
$G - D = M$
OR
$M = G - D$



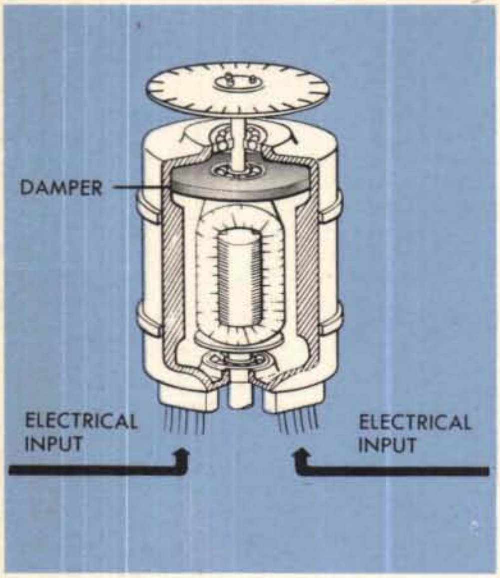
$G + D = -M$
OR
$M = -G - D$



$G - D = -M$
OR
$M = D - G$

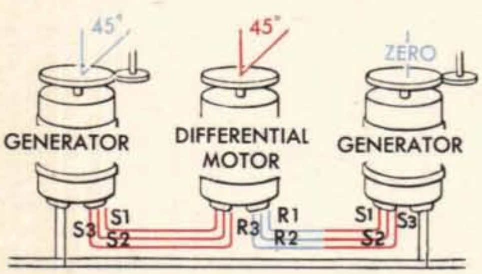


$G + D = M$
OR
$M = G + D$



The DIFFERENTIAL

The synchro differential motor is designed like the differential generator. The only difference is that it has a damper to prevent oscillation and spin.

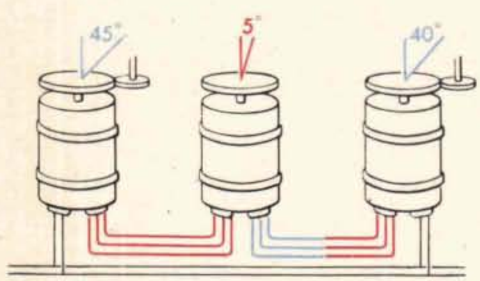


The synchro differential motor receives two electrical inputs from two synchro generators.

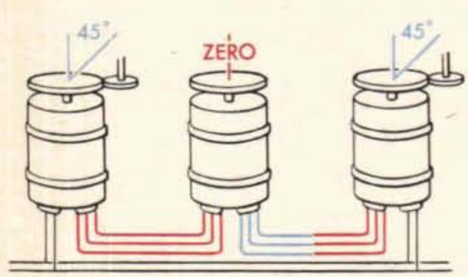
If the synchro team is wired, as shown here, operation will be as follows:

When the rotor of one generator is turned 45° clockwise, the rotor of the differential motor turns 45° clockwise.

The rotor of the second generator being on zero, it transmits no change of signal.



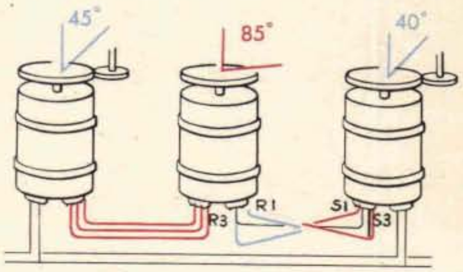
When the rotor of the first generator is turned 45° clockwise, and the rotor of the second generator is turned 40° clockwise, the rotor of the motor indicates 5° clockwise. This is because the rotors of the second generator and the motor turn in opposite directions. The signal of 45° clockwise from the first generator is partially cancelled by the signal from the second generator, which causes the dial on the motor to turn counterclockwise.



If both generator rotors are turned 45° in the same direction the motor will remain at zero, the signal from the first generator cancelling the signal from the second.

MOTOR

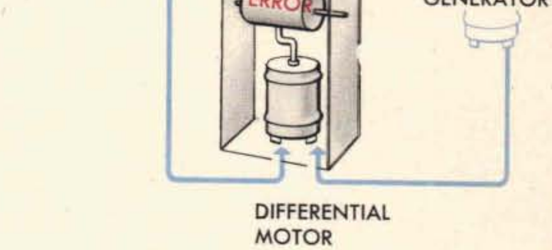
If the synchro setup is wired as shown here, the values of 45° and 40° transmitted by the generators will be added together, and the rotor of the motor will turn through 85°.



To summarize: Either the difference between two transmitted values, or the sum of two transmitted values, can position the differential motor.

An example of how the differential motor is used is found in a testing device called an Error Recorder. This device uses a differential motor to measure continuously the difference between the *signal* to a given mechanism, and the *actual position* of that mechanism. Here is one of the ways it can be used:

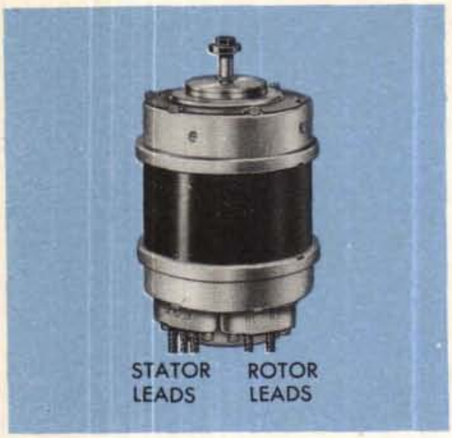
A mechanism known as a dummy director drives a synchro generator which transmits a train signal to position a gun. The same signal goes to one side of the differential motor in the error recorder.



As the gun trains, it drives a synchro generator. This generator sends a signal to the other side of the differential motor.

The difference between the position of the generator in the dummy director and the generator driven by the gun is shown by the differential motor. This difference is the error in gun train.

The CONTROL TRANSFORMER

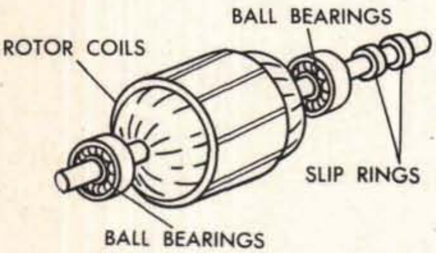


The control transformer is another kind of synchro. Both the synchro motor and the control transformer receive information electrically from a synchro generator, but their outputs differ.

The synchro motor output is the *rotation* of the rotor shaft.

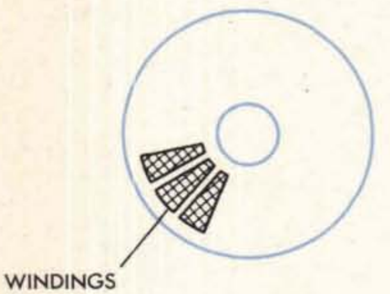
The control transformer output is a *voltage* induced in the rotor coils.

The stator of the control transformer is similar to the stators of other synchro units, but the coils are wound with more turns.



The rotor winding of the control transformer, however, while it resembles that of a differential synchro in appearance, differs considerably from the rotor winding of other types of synchros. It consists of a number of coils which are set in slots around the rotor, and although these coils are connected in series like the coils of other types of synchro rotors, the manner in which the turns are located around the rotor is a characteristic of the control transformer.

The two ends of the rotor winding are connected to slip rings on the shaft. Brushes which bear against these slip rings are connected to *R1* and *R2* leads, as in the case of standard synchro units.

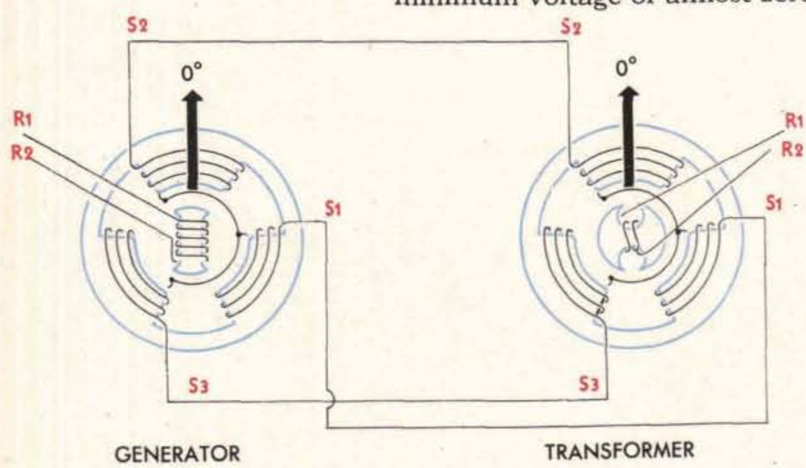


CROSS SECTION OF CONTROL TRANSFORMER ROTOR

The diagram below shows a generator and control transformer hook-up.

Note that when the rotor of the generator is in "electrical zero" position it lines up with the *S2* winding of its stator; but when the rotor of the control transformer is in zero position it is turned at 90° to the *S2* winding.

It will be remembered that, at point of synchronism, the rotor of a synchro motor takes a position which induces the proper maximum voltages in the stator coils—equal and opposite to the voltages produced by rotation of the generator rotor. However, when the rotor of a control transformer is brought to its position of synchronism, or "correspondence" as it is called, a minimum voltage of almost zero is induced in the rotor.

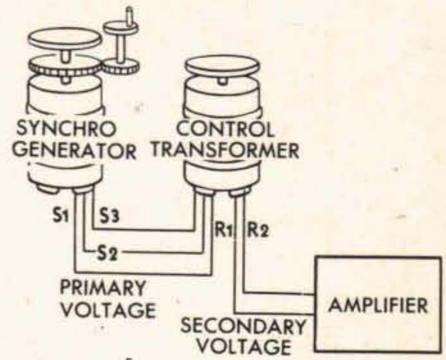


THE TRANSFORMER ROTOR COILS ACT AS IF THEY WERE CONCENTRATED IN ONE COIL WOUND AS SHOWN HERE.

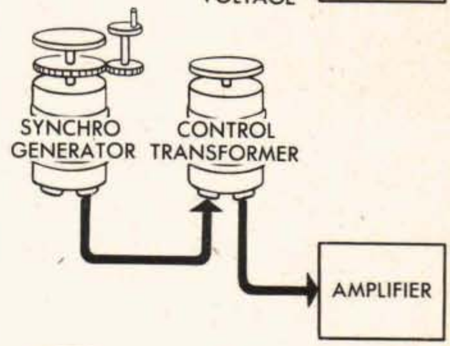
How a control transformer is used

A control transformer, like a synchro motor, is teamed to work with a synchro generator.

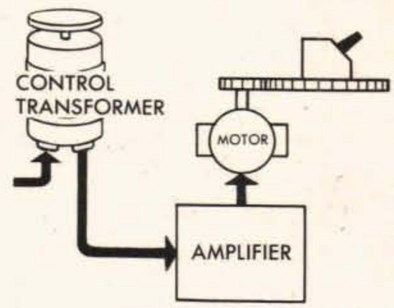
The rotor of the control transformer is NOT connected to the power supply. Instead, the *R1* and *R2* leads are usually connected to vacuum tubes in a power amplifier circuit.

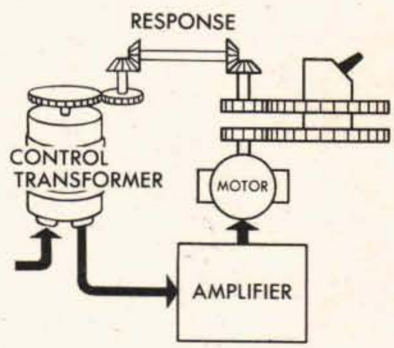


The stator of the generator supplies a primary voltage to the stator of the transformer, and the stator coils in the transformer induce a secondary voltage in the transformer's rotor winding. This secondary voltage is transmitted over the *R1* and *R2* leads to the amplifier. Thus the synchro generator supplies a signal to the transformer, and the transformer, in turn, operates the amplifier.



The amplifier controls a power motor, which is used to train a gun, or a searchlight, or to rotate other mechanisms. The object which is trained or rotated—in this example, a gun—is geared to the rotor of the control transformer. As the motor runs, rotation of the gun acts through this response gearing and turns the rotor of the transformer. When the rotor of the transformer has been turned an amount equal to the signal from the generator, the output voltage of the control transformer drops to zero, causing the power motor and gun to cease turning.



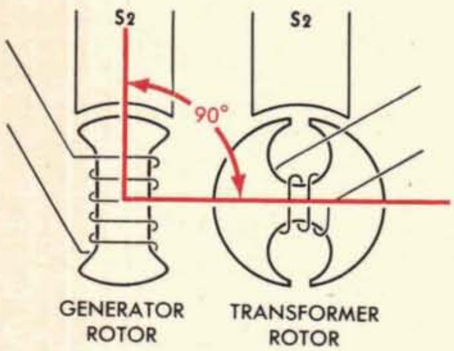


In a similar manner, the gun can be elevated or depressed.

Difference between a control transformer and other synchro units

1. When the stator coils of a control transformer are energized by the generator they do not turn the rotor. They merely induce a voltage in the rotor. It is this voltage, not rotor movement, which signals a mechanism.
2. Because the rotor does not turn in signalling a mechanism, rotor bearing friction does not affect the signal.
3. The rotor of a control transformer is turned *mechanically* by the response line from the mechanism being controlled.
4. Whatever the position of the rotor, the transformer rotor windings are so arranged that, the currents induced in the rotor do not affect the currents that flow in the stator.
5. A synchro generator can drive fewer control transformers than synchro motors, because a control transformer is not connected to the power supply. All of the energy needed by a control transformer must be supplied from the stator of the synchro generator.

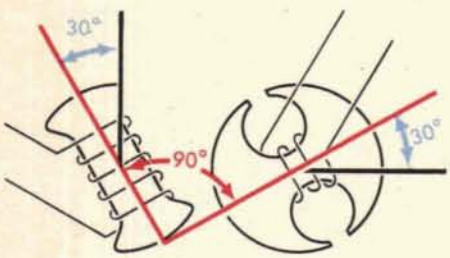
How the control transformer operates



To understand how the control transformer operates, it is best to start with the synchro generator and the transformer on elecrical zero.

The generator rotor lines up with the *S2* winding when in zero position, whereas the transformer rotor is turned 90° from its *S2* winding. The transformer rotor coil, therefore, lies at right angles to the generator rotor coil.

Whenever the two rotor coils are at right angles to each other, they are said to be *in correspondence.*



No matter to what position the generator rotor may be turned, the rotor of the transformer can be turned to bring the rotors into correspondence. For instance, here the generator rotor has been moved 30° from its zero position. By rotating the transformer 30° also, the two rotors are again brought into correspondence.

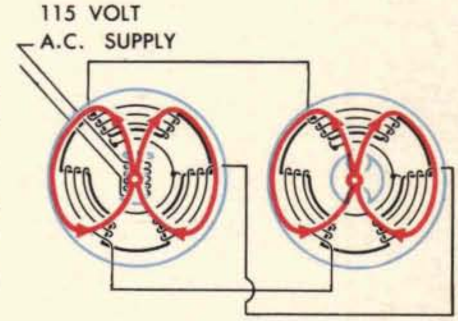
When the rotor of the generator is turned, four things happen in the transformer.

1. The magnetic fields in the generator and transformer rotate.
2. Voltage is induced in the transformer rotor.
3. Polarity of the transformer rotor leads, with respect to the voltage energizing the generator rotor, is established.
4. The transformer rotor is rotated toward the position of correspondence by the response gearing.

Magnetic fields

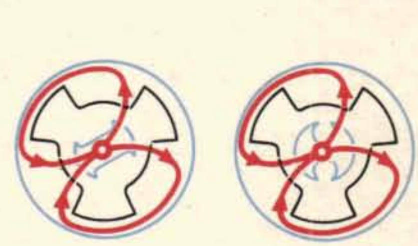
The magnetic field set up by the rotor of a synchro generator, when it is supplied with 115 volts A.C., cuts the stator windings of the generator and induces voltages in them.

When the generator is connected to a control transformer, these voltages are transmitted to the stator windings of the transformer and a similar magnetic field is set up in the transformer, just as in the case of the synchro motor.



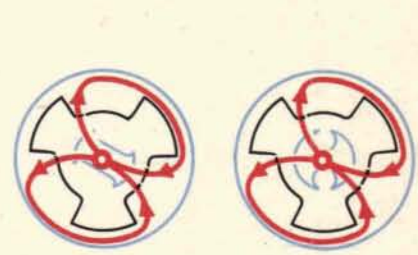
If the rotor of the generator is turned clockwise, the generator field rotates clockwise.

The transformer field also turns clockwise *by an equal amount* because the transformer field is set up by the generator field.



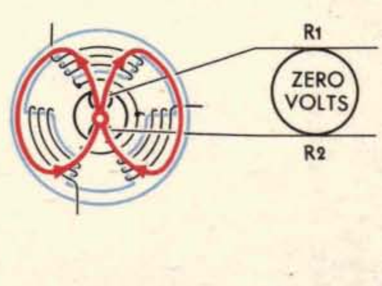
If the rotor of the generator is turned counterclockwise, both fields also rotate counterclockwise the same amount.

The transformer's field movement depends upon rotation of the generator rotor, and takes place regardless of the position of the transformer rotor.

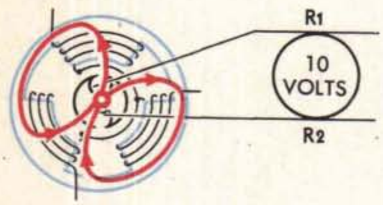


GENERATOR TRANSFORMER

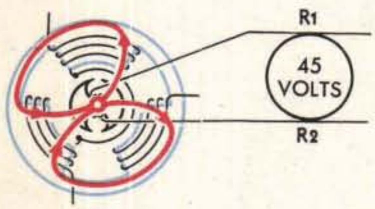
When the rotor of the transformer is in correspondence with the rotor of the generator, a voltmeter will show almost zero voltage (0.03 to 0.3 volts) across *R1* and *R2*. This is because the coils of the rotor winding are lying parallel to the path taken by the lines of force (or flux) of the magnetic field. In this position, the lines of force do not cut the coils, and only a minimum of voltage, due to small eddy currents, is produced.



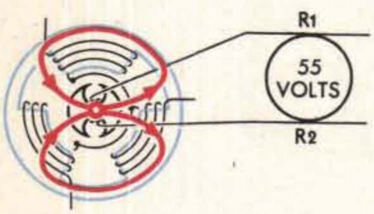
Change of VOLTAGE of the transformer rotor leads



When the field is turned 10°, approximately 10 volts are measured across *R1* and *R2*.



When the field is turned 60°, approximately 45 volts are measured across *R1* and *R2.*



When the field is turned 90°, approximately 55 volts are measured across the rotor leads. This is the maximum voltage which can be induced in the rotor winding of the transformer.

When the field is turned 180°, the transformer's output voltage falls to its minimum. The coils of the rotor winding are again parallel to the lines of force of the stator field, and the transformer rotor is once more in correspondence. When the field is turned 270°, the output voltage rises to its maximum of 55 volts. At 360°, the output voltage is again at a minimum because it is then at the same position as at 0°. There are, therefore, two points in the rotation of the field, 0° and 180°, at which the output voltage from the transformer rotor is at a minimum.

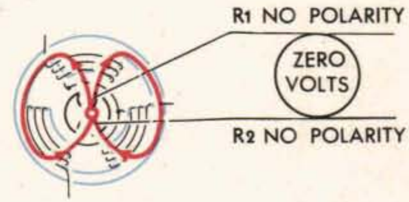
If the field is rotated the same amounts counterclockwise, instead of clockwise, from either the 0° or 180° position, the same voltages will be obtained. This means that for a given amount of rotation, equal voltages will be obtained regardless of the direction in which the field is rotated. However, polarity will change as the field is rotated through the two points of correspondence which lie 180° apart.

Summing up:

1. When the rotors ARE in correspondence, *there is minimum voltage* (almost zero) across the transformer rotor leads.
2. When the rotors are NOT in correspondence, *there is more than minimum voltage* across the transformer rotor leads.

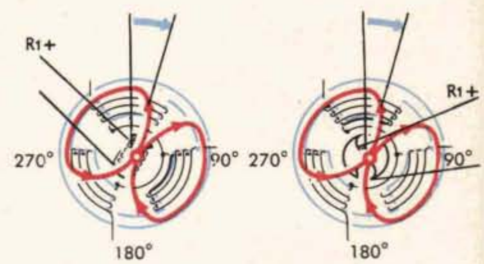
Change of POLARITY of the transformer rotor leads

The position of the magnetic fields in relation to the rotor zero position determines the polarity of the transformer's rotor leads.



When the coils of the transformer rotor winding lie parallel to the path taken by the lines of force, there is no voltage across *R1* and *R2*. Because there is no voltage, there can be no polarity.

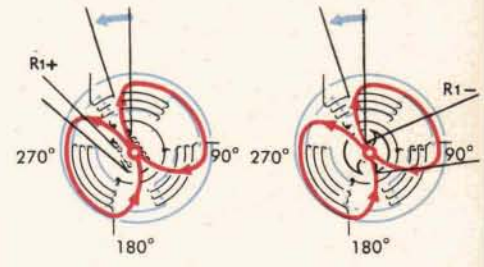
When the rotor of the generator is turned clockwise from the rotor zero position, both magnetic fields turn clockwise, and a voltage is set up across the transformer's *R1* and *R2* leads.



GENERATOR TRANSFORMER

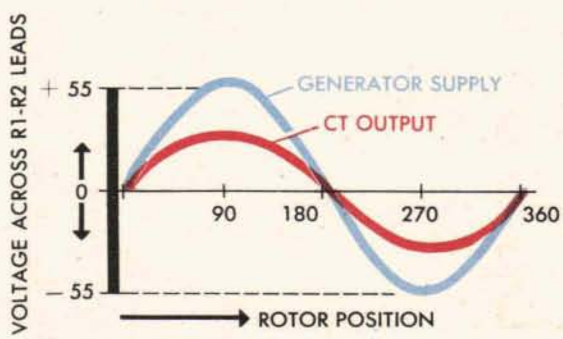
If the polarity of this voltage, at a given instant, is positive when the energizing voltage to the generator rotor is positive, then lead *R1* of the transformer is plus when lead *R1* of the generator is plus. The induced voltage across the transformer leads is in phase with the A.C. supply to the generator rotor.

When the generator rotor is turned counterclockwise from the rotor zero position, the voltage across the *R1* and *R2* leads of the control transformer will be negative at the instant the energizing voltage applied to the generator rotor is positive. The voltage from *R1* to *R2* on the control transformer will be 180° out of phase with the A.C. voltage from *R1* to *R2* on the generator. The polarity of lead *R1* of the transformer is now minus when lead *R1* of the generator is plus.

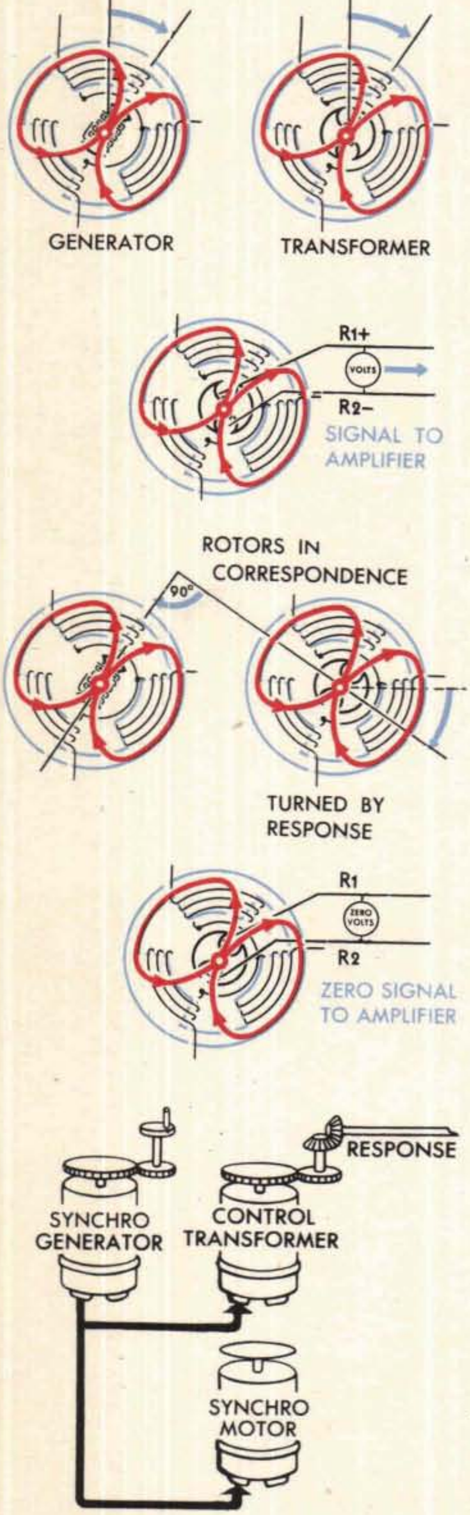


The polarity of the control transformer output voltage is determined by the position of the magnetic fields in relation to the rotor zero position.

It has now been established that the output of the control transformer is a voltage which varies in magnitude and shifts polarity with the deviation of the transformer rotor from the position of correspondence. This output is a signal which can be amplified by means of a follow-up and used to position mechanisms.



Response



Since almost no voltage is induced in the rotor of the transformer when the generator and transformer rotors are in correspondence (at right angles), voltage from the transformer to the amplifier can be reduced to zero by bringing the transformer rotor into correspondence with the generator rotor.

This is done by means of the response gearing.

In this example, an input to the generator has turned the generator rotor clockwise. Consequently, the magnetic fields are turned clockwise.

A voltage is induced in the rotor of the transformer, and this voltage is transmitted to the amplifier.

When rotation of the generator rotor stops, the rotation of the magnetic fields stops.

When the transformer rotor is turned by the response until it is in correspondence with the rotor of the generator the voltage across the *R1* and *R2* leads of the transformer falls almost to zero—because the coils of the rotor winding lie parallel to the path taken by the lines of force in the magnetic field.

With voltage nearly zero, the signal to the amplifier ceases.

In practice, the rotating of the magnetic fields and the response action are almost simultaneous, which means that the rotor of the transformer is brought into correspondence within a fraction of a second after input to the generator stops. Rotation of the gun, or searchlight, therefore, can be regarded as simultaneous with transmission of the signal.

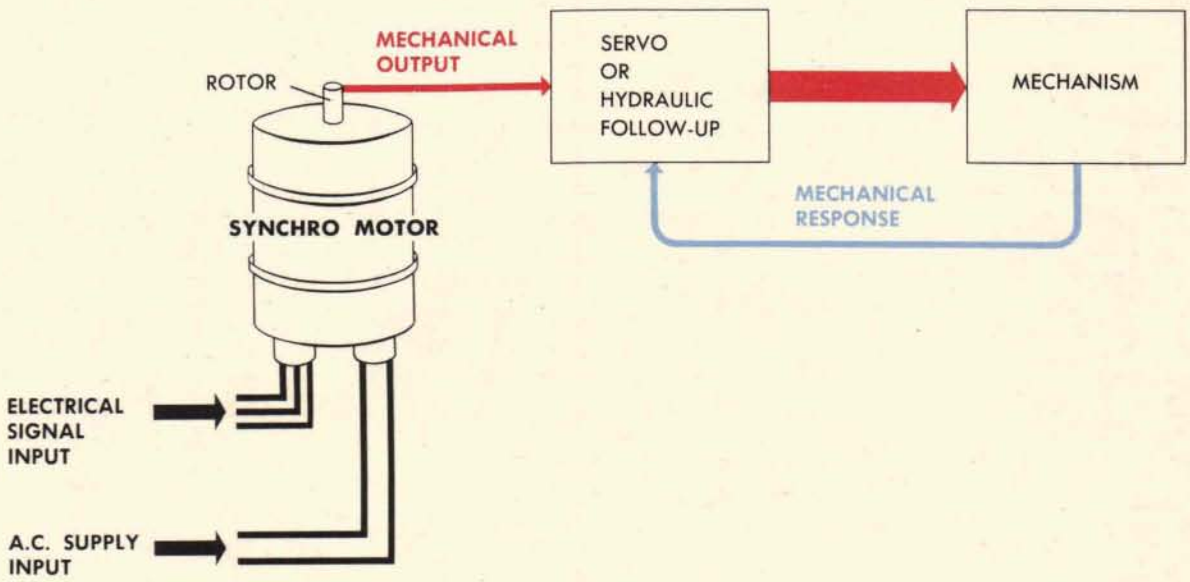
A control transformer and synchro motor on the same line

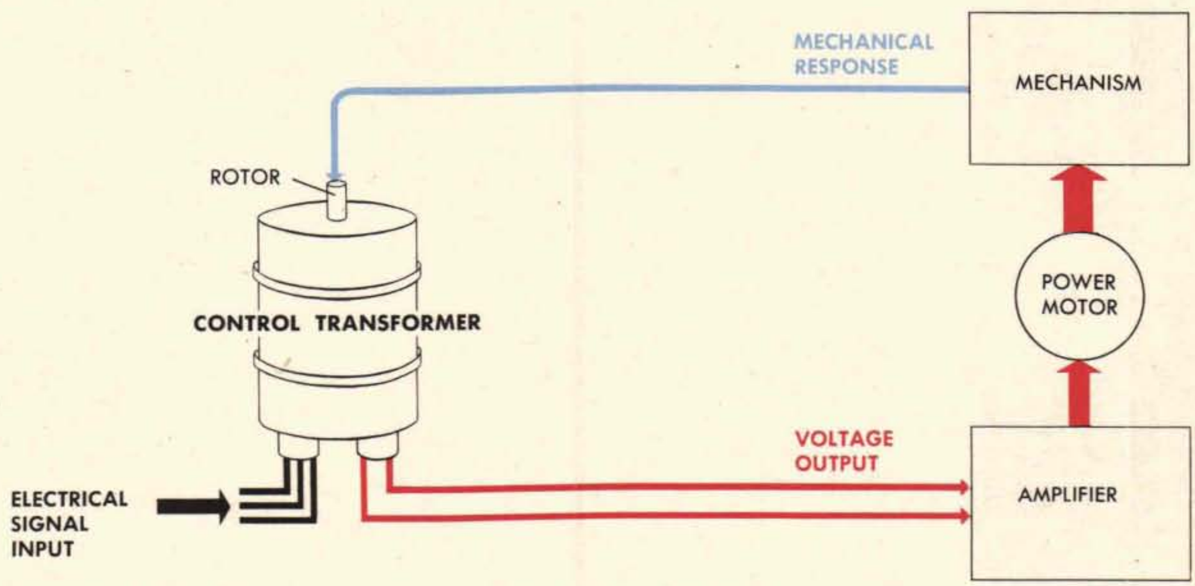
A control transformer can be added to a synchro generator-synchro motor circuit so that both transformer and motor, each positioning separate mechanisms, can receive signals from the same generator.

Rotation of the transformer rotor by the response has no effect upon the operation of the motor. This is because the position of the transformer's rotor has practically no effect upon the currents that flow in the transformer stator coils, and therefore there is no "kick back" to the system when the transformer rotor is turned by the response.

From this it can be seen that if the power is shut off at the amplifier, and the gun or the searchlight normally controlled by the transformer is positioned manually, the resulting rotation of the transformer rotor will not affect other transformers or synchro motors connected to the same line.

Comparison between a SYNCHRO MOTOR hook-up and a CONTROL TRANSFORMER hook-up





TYPES of SYNCHRO GENERATORS

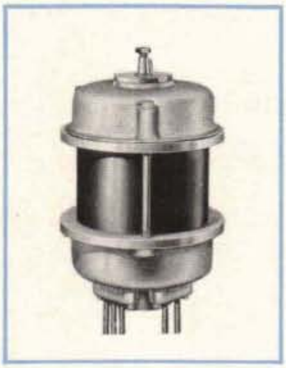
Diameter dimensions given are the maximum outside diameters. Length dimensions are over-all (over-the-shaft) lengths.

1G

Shaft Ext.: Tapered
115 V. Pri., 90 V. Sec.
Avg. Error: 0.5 deg.
Max. Error: 1.5 deg.
Length: 3.90 in.
Diam. 2.25 in.

5G

Shaft Ext.: Straight
115 V. Pri., 90 V. Sec.
Avg. Error: 0.2 deg.
Max. Error: 0.6 deg.
Length: 6.05 in.
Diam. 3.625 in.

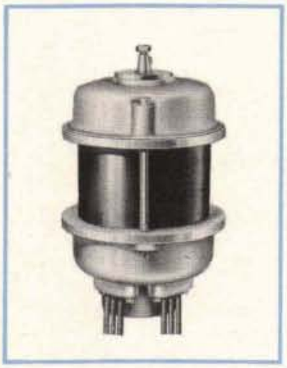


6G

Shaft Ext.: Tapered
115 V. Pri., 90 V. Sec.
Avg. Error: 0.2 deg.
Max. Error: 0.6 deg.
Length: 7.22 in.
Diam. 4.5 in.

7G

Shaft Ext.: Tapered
115 V. Pri., 90 V. Sec.
Avg. Error: 0.2 deg.
Max. Error: 0.6 deg.
Length: 8.90 in.
Diam. 5.75 in.



6DG

Shaft Ext.: Tapered
90 V. Pri., 90 V. Sec.
Avg. Error: 0.2 deg.
Max. Error: 0.6 deg.
Length: 8.53 in.
Diam. 4.50 in.

7DG

Shaft Ext.: Tapered
90 V. Pri., 90 V. Sec.
Avg. Error: 0.2 deg.
Max. Error: 0.6 deg.
Length: 9.21 in.
Diam. 5.75 in.

•5SDG - 5DG

Shaft Ext.: Straight
90 V. Pri., 90 V. Sec.
Avg. Error: 0.2 deg.
Max. Error: 0.6 deg.
Length: 6.36 in.
Diam. 3.625 in.

•S denotes special units — in this case 400 cycles.

TYPES of SYNCHRO MOTORS

3F

Shaft Ext.: Straight
115 V. Pri., 90 V. Sec.
Avg. Error: 0.2 deg.
Max. Error: 0.6 deg.
Length 5.2 in.
Diam. 3.1 in.

1F

Shaft Ext.: Tapered
115 V. Pri., 90 V. Sec.
Avg. Error: 0.5 deg.
Max. Error: 1.5 deg.
Length 3.90 in.
Diam. 2.25 in.

5B

Shaft Ext.: Straight
115 V. Pri., 90 V. Sec.
Avg. Error: 0.2 deg.
Max. Error: 0.6 deg.
Length 6.77 in.
Diam. 3.39 in.

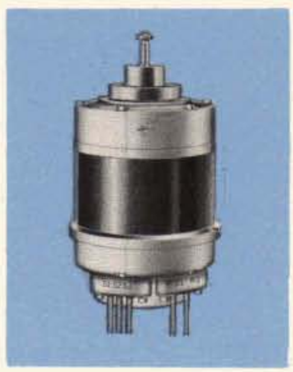
5D

Shaft Ext.: Straight
90 V. Pri., 90 V. Sec.
Avg. Error: 0.2 deg.
Max. Error: 0.6 deg.
Length 6.35 in.
Diam. 3.625 in.

5F – •5SF

Shaft Ext.: Straight
115 V. Pri., 90 V. Sec.
Avg. Error: 0.2 deg.
Max. Error: 0.6 deg.
Length 6.05 in.
Diam. 3.625 in.

•**S** denotes special units – in this case 400 cycles.



•5N

Shaft Ext.: Straight
115 V. Pri., 90 V. Sec.
Avg. Error: 0.2 deg.
Max. Error: 0.6 deg.
Length 6.63 in.
Diam. 3.625 in.

•**N** denotes nozzle mounting.

CONTROL TRANSFORMERS

1CT

Shaft Ext.: Straight
90 V. Pri., 55 V. Sec.
Av. Error: 0.166 deg.
Max. Error: 0.5 deg.
Length 3.90 in.
Diam. 2.25 in.

5CT

Shaft Ext.: Straight
90 V. Pri., 60 V. Sec.
▲Avg. Error: 0.12 deg.
Max. Error: 0.33 deg.
Length 6.05 in.
Diam. 3.625 in.

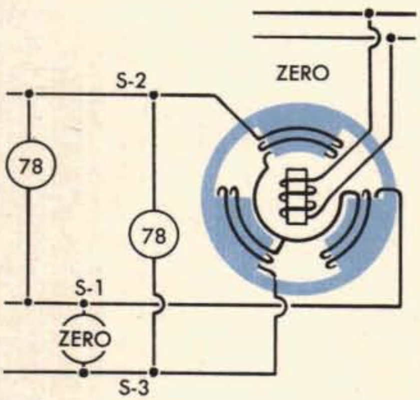
3HCT and **5HCT** are designed for high speed applications. Avg. and Max. Errors same as for *5CT*.

▲Error in control transformers is expressed as degrees of rotation of the magnetic field set up by the currents in the stator.

Setting SYNCHROS

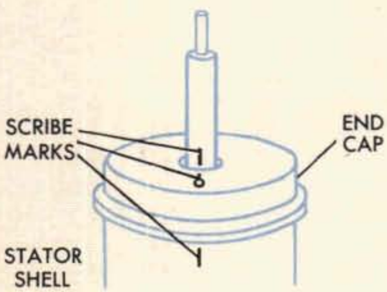
Synchro units are used to transmit values by angular movement. *A common reference point is needed* to which these units may be set before being connected.

In setting synchros, *electrical zero* is used as this common reference point.



The electrical zero point is one of two definite positions of the rotor with respect to the stator. The synchro is in either one of these two positions when the rotor is in such a position that the voltage across the *S1* and *S2* leads is equal to the voltage across the *S2* and *S3* leads, and there is zero voltage across the *S1* and *S3* leads.

A means must be provided to find which of these two positions is the electrical zero position.

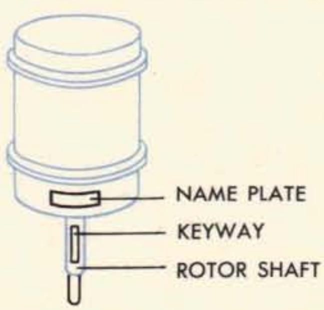


On some synchros *scribe marks* indicate approximately the position of electrical zero. Sometimes the scribe marks cannot be seen when the synchro is installed in the instrument. Some of the older synchros do not have scribe marks. For these reasons it is necessary to know how to find electrical zero.

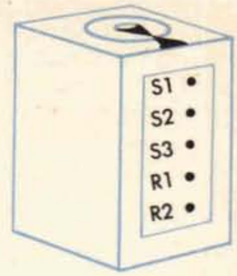
Here are two methods:

The Standard Motor Method

The Electrical Lock Method



NEW FORD GENERATORS ARE APPROXIMATELY ON ELECTRICAL ZERO WHEN THE ROTOR KEYWAY IS LINED UP WITH THE CENTER OF THE NAMEPLATE.

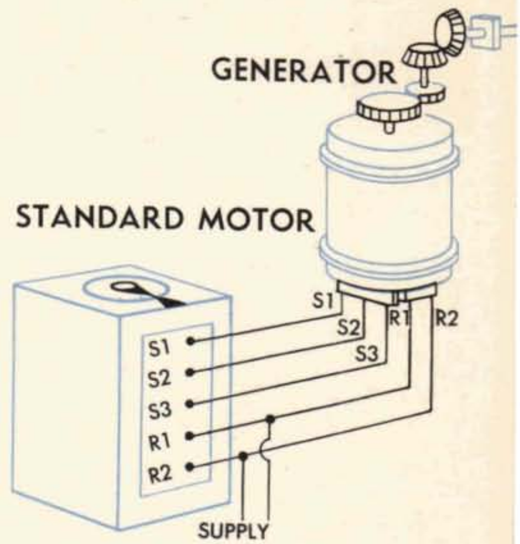


The STANDARD MOTOR METHOD

In the Standard Motor Method a synchro motor that has been accurately set on electrical zero is used to set other synchro motors and generators.

The motor is mounted in a box and has a pointer dial to indicate the position of the rotor. The box has an index mark and when the pointer and the index mark are lined up the motor is at electrical zero.

A button on this box can be pressed down to lock the standard motor at the electrical zero position indicated on the dial.



How to use the standard motor to set a generator

Connect the standard motor to the generator–

S1 to *S1* *S2* to *S2* *S3* to *S3* *R1* to *R1* *R2* to *R2*

Then supply 115 volts 60 cycle A.C. across *R1* and *R2*.

The rotor of the standard motor will snap into synchronism with the generator rotor and the standard motor dial will indicate the amount the generator is off electrical zero.

Here the standard motor dial indicates the generator is on electrical zero.

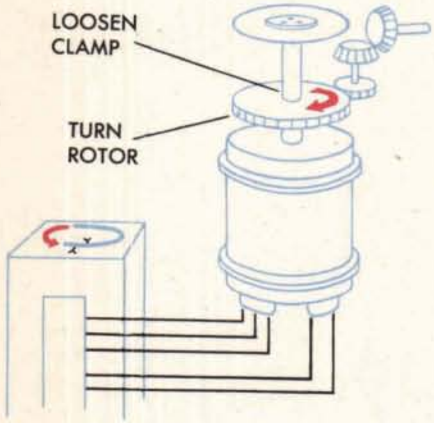
Here the standard motor dial indicates the generator is not on electrical zero and should be set according to the instructions on the following page.

How to use the standard motor to set another motor

The electrical hook-up is exactly the same. The standard motor is locked at zero by means of the push button. This will position the motor that is being set at electrical zero.

To correct when a SYNCHRO is off

There are several ways to correct the setting when a synchro generator is off electrical zero, depending upon the method of clamping.

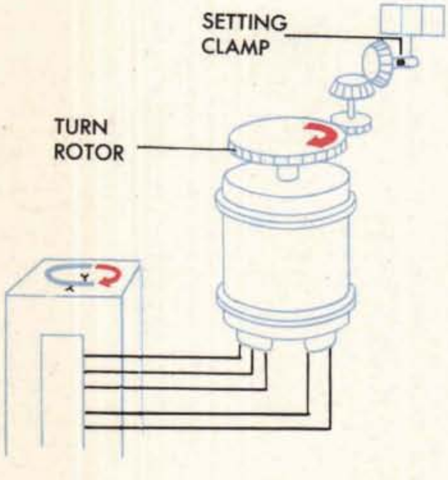


Where a clamping device is used to hold the generator dial to its rotor, loosen the clamping device and turn the rotor.

The generator will transmit a signal to the standard motor causing its dial to turn.

Turn the generator rotor until the standard motor dial reads zero.

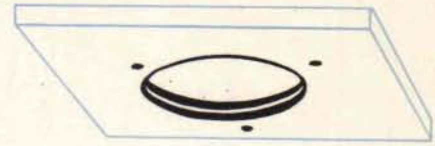
Tighten the clamping device with the generator dial and standard motor dial both on zero.



Where a setting clamp connects the generator rotor to its dial or counter, loosen the clamp and turn the rotor and gearing until the standard motor dial reads zero.

With the standard motor dial reading zero, position the generator dial or counter on zero. Tighten the setting clamp.

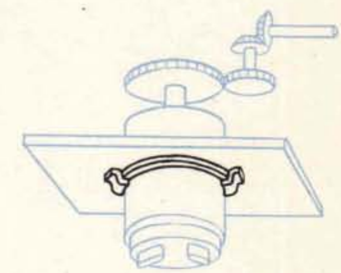
ELECTRICAL ZERO



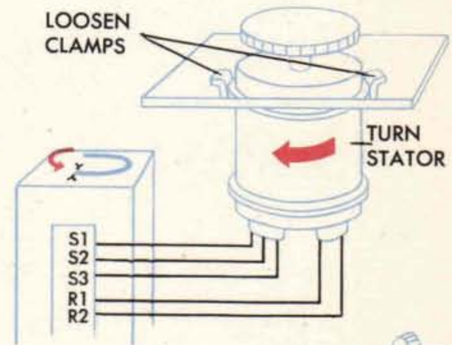
Some installations do not have a dial clamping device. Then the correction is made by changing the mounting of the synchro.

Here is a typical synchro mount.

A plate is machined so that it has a hole with a shoulder all the way around.

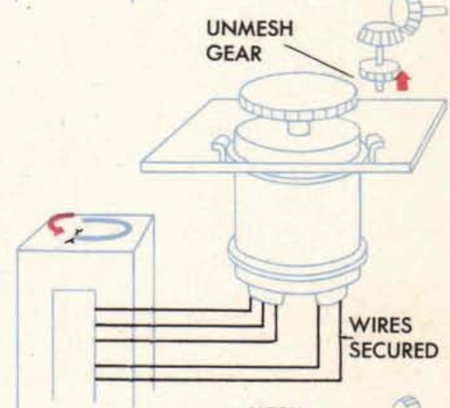


The flange on one of the end caps fits into the hole and is held against the shoulder by clamps that hold the synchro in place.

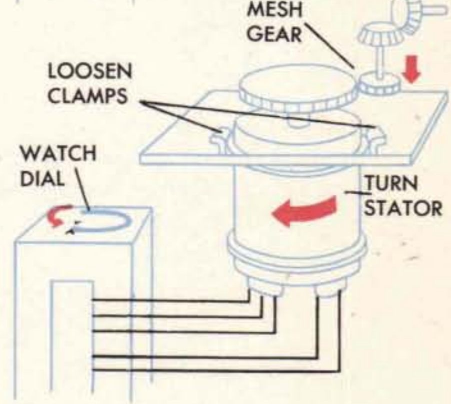


If the motor dial does not indicate zero when the current is connected, loosen the clamp screws on the generator or motor being set and turn its stator until both dials read zero; then tighten the clamp screws.

The stator of the generator is turned in the *opposite direction* to the rotor of the motor because the rotor of the generator is being held by gearing.



If the wires on the generator are secured and will not allow the stator to be turned far enough to zero the generator, unmesh the gears that drive the rotor. Turn the rotor of the generator until the standard motor dial reads zero.

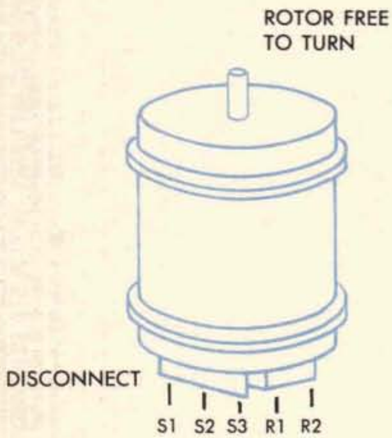


Remesh the gears to the nearest tooth.

Then if the dial is slightly off zero, loosen the clamps that hold the stator and turn the stator until the dial reads zero.

Tighten the clamps.

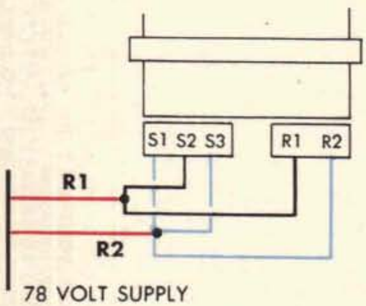
The ELECTRICAL LOCK METHOD



The Electrical Lock is another method of finding electrical zero.

First disconnect from the rest of the system the synchro motor or generator that is to be set.

Be sure the rotor is free to rotate.



Then connect *S2 to R1* and *S1 and S3 to R2* and put a 78-volt supply on the *R1* and *R2* leads.

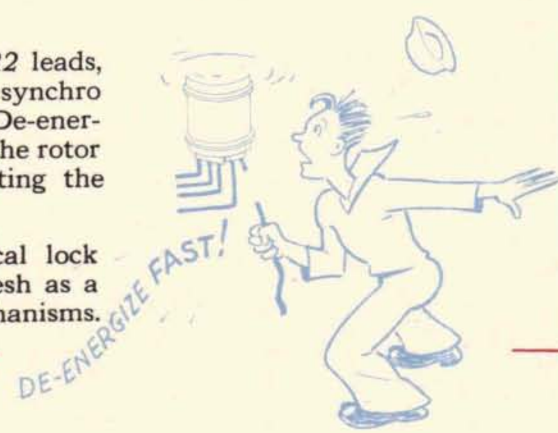
The rotor will snap around and the synchro will be *locked on electrical zero.*

Where a 78 volt supply is not available, a 115-volt supply may be used. It must be left on only for a few minutes—not longer than three or four, because the synchro may burn out if it remains on.

CAUTION:

When the power is supplied to the *R1* and *R2* leads, the rotor may whirl around very rapidly if the synchro is too far off electrical zero. This is dangerous. De-energize the synchro immediately and try to bring the rotor nearer to the zero position before reconnecting the power.

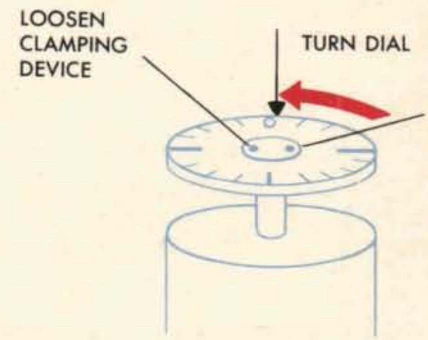
Before checking a generator by the electrical lock method, take the gear on the rotor out of mesh as a precaution against damaging gearing and mechanisms.



Resetting a dial

If the synchro is on zero but the dial is not, loosen the dial clamping device; then turn the dial until it reads zero. Tighten the clamping device.

There are several types of clamping devices. Find out how the dial is clamped, and use the proper tools.

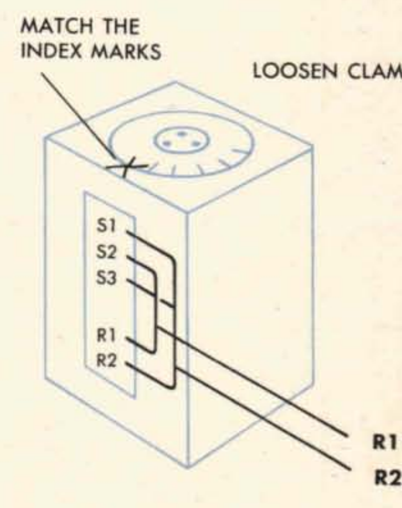


How to check the standard motor

If there is any doubt about the accuracy of the standard motor, check it by the Electrical Lock Method.

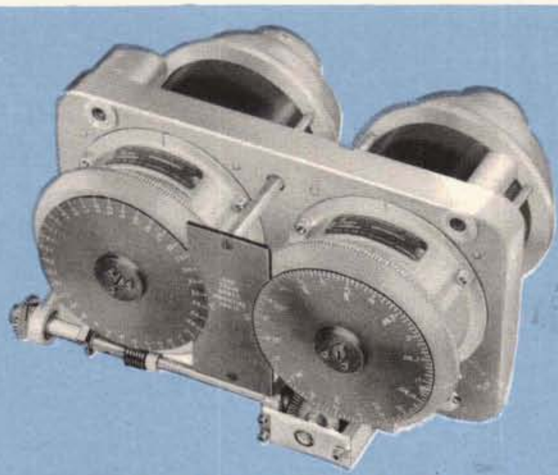
When the standard motor is correctly set, the index marks will match whenever the leads are connected.

To correct the setting if the index marks do not match, loosen the dial clamp and turn the dial.



SYNCHRO TRANSMITTERS

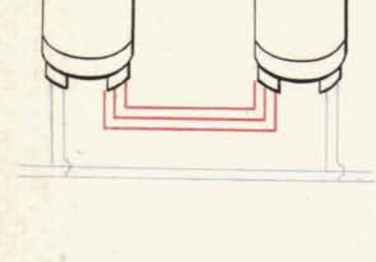
SINGLE SPEED TRANSMITTER



DOUBLE SPEED TRANSMITTER

SINGLE SPEED TRANSMISSION

A single speed transmission system consists of a single generator transmitting a signal to single synchro motors as shown here. The single generator is known as a "single speed transmitter," and each synchro motor as a "single speed receiver." (In many cases, the synchro motor is used with a servo and a follow-up. This type of receiver is described in the next chapter.)

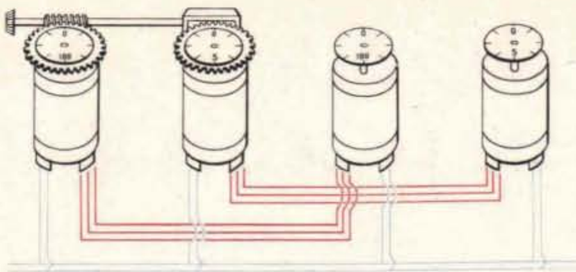


Bearing friction, because of the low torque at the synchronizing point, sometimes causes slight errors in the positioning of the motor rotor. Single speed transmission is sufficiently accurate to take care of the following kinds of quantities:

1 Quantities which do not have a definite reference, such as increments of generated range or bearing. When used to transmit such quantities, a single speed transmitter can be made as accurate as desired simply by gearing it to transmit a small value per revolution. If a change of range transmitter is geared to transmit 100 yards of range change per revolution, a $\frac{1}{2}°$ of error in the position of the motor rotor will result in a transmission error of less than 1 foot of range change.

2 Quantities having a small range of values, such as parallax corrections in the Computer Mark 1. Values of parallax corrections are only computed between $+12°$ and $-12°$ so that if one revolution of the generator rotor represents, say, $25°$ of parallax, an error as large as $\frac{1}{2}°$ in the position of the motor rotor will represent an error of only 2 minutes in the value which is being transmitted.

DOUBLE SPEED TRANSMISSION



This system consists of a pair of generators geared together and transmitting to one or more pairs of synchro motors. The "coarse" generator is usually worm driven and usually rotates once for either 18 or 36 revolutions of the "fine" generator.

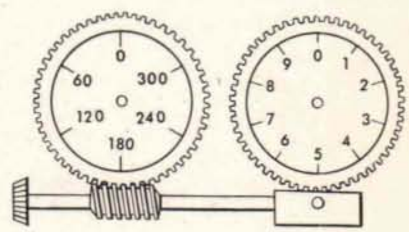
The two generators, geared together, are known as a "double speed transmitter," and the two synchro motors are known as a "double speed receiver." (In many cases, the synchro motors are used with a servo and a follow-up control. This is described later.)

Double Speed Transmission is used when very accurate transmission is necessary and the range of values to be transmitted is too great for accurate single speed transmission. An example of its use is the gun train order transmitter unit in the Computer Mark 1.

A dial on one generator has graduations from 0° to 360° so that one revolution of the dial equals 360° of bearing. This is the "coarse" dial.

The dial on the other generator has graduations from 0° to 10° so that one revolution of the dial equals 10° of bearing. This is the "fine" dial.

The gearing between the two generators is such that while the coarse dial is revolving once—the fine dial must turn 36 times.

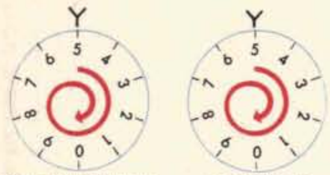


NOTE: The terms *single speed* and *double speed* when used with transmitters and receivers must not be confused with *one speed*, or *two speed* transmission.

When referring to transmission, *one speed* means that one revolution of a transmitter rotor represents the whole range of values concerned with that transmitter. For instance, one revolution of a rotor which represents 360° takes care of all values of bearing. A rotor representing 180° of bearing per revolution would have to be turned twice to transmit the full 360° of bearing, and therefore gives *two speed* transmission. A rotor representing 10° of bearing per revolution gives *36 speed* transmission.

The term *single speed* applies to a transmission system in which only one speed of transmission is used, while the term *double speed* denotes a transmission system in which two different speeds are used to obtain increased accuracy in transmitting an order. Thus a *single speed* system might transmit at 10 speed and a *double speed* system at 1 speed and 36 speed.

The FINE CONTROL cannot operate successfully alone



TRANSMITTER RECEIVER

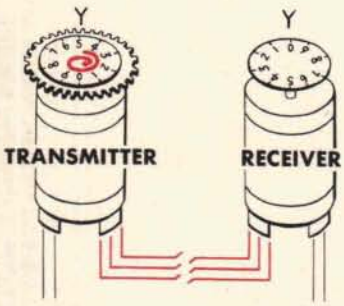
* IF FINE CONTROL ONLY WERE USED

At first glance, it might appear that a *fine* control system could take care of the whole operation of positioning a mechanism without assistance from a *coarse* control. But the coarse control plays two important roles:

1 Assume for a moment that a synchro team uses only the fine control principle, the transmitter and receiver dials being graduated from 0° to 10°.

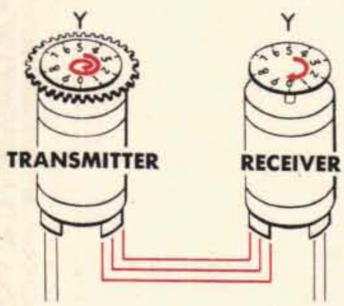
If a value of 15° of Target Bearing is now cranked into the transmitter, the rotor of the fine motor will turn 1½ times, and the value 5 will appear opposite each index.

Since only the fine control is used, the same value 5 would appear if 5°, 15°, 25°, or 35°, etc., were cranked in.



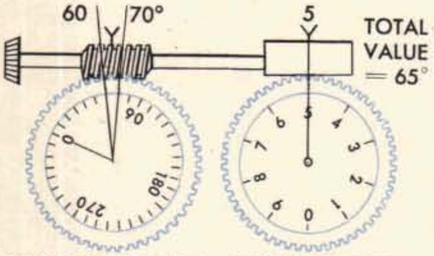
2 Suppose the leads between a single speed transmitter and receiver are disconnected, and the rotor of the transmitter generator is turned 1½ times, so that the graduation 5 comes opposite the index mark.

When the leads are again connected, the graduation 5 will come to the index of the receiver dial when the rotor of the synchro motor has made only ½ turn.



Although both transmitter and receiver dials now read 5°, the rotor of the receiver is one whole revolution (10°) out of synchronism with the transmitter.

It is impossible to read off total values transmitted from one fine dial to the other after one revolution has been made.



COARSE CONTROL FINE CONTROL

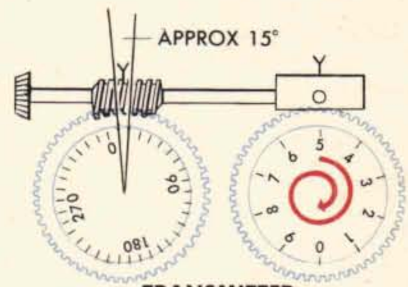
BOTH TRANSMITTER AND RECEIVER DIALS APPEAR LIKE THIS WHEN COARSE AND FINE CONTROLS ARE USED

By using the coarse control with the fine control, accurate total values can be read on the dials. The coarse control transmits a rough total value. Its dial is read to obtain the value transmitted by complete revolutions of the fine control.

The total value transmitted is read by adding the fine dial value to the value of the lower of the two graduations near the coarse dial index.

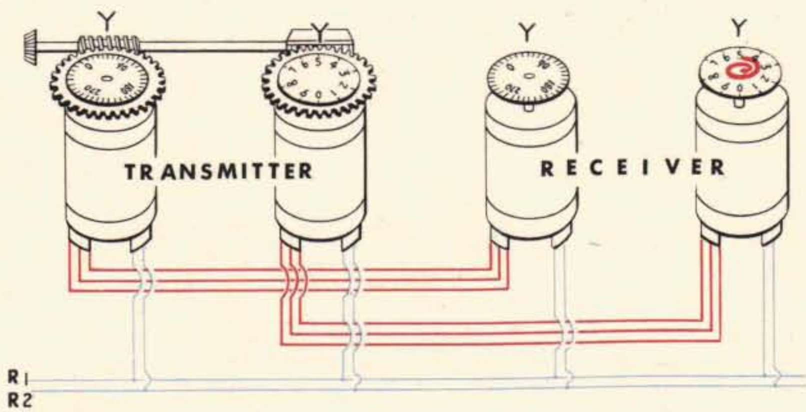
Use of the COARSE CONTROL synchronizes the receiver with the transmitter

Now assume that a coarse control is added to the fine—but the leads from the double speed transmitter to the receiver are not yet connected.



When a value of 15 is cranked into the double speed transmitter, dials of the coarse and fine generators appear as shown here (the fine dial having turned 1½ times).

When the circuit is completed the rotor of the coarse motor turns until its dial registers the same amount as the coarse generator, and the rotor of the fine motor turns until its dial reading conforms to that of the fine generator. *Readings taken from the two dials of the double speed receiver give the true total value of the signal transmitted.*



SUMMARY:

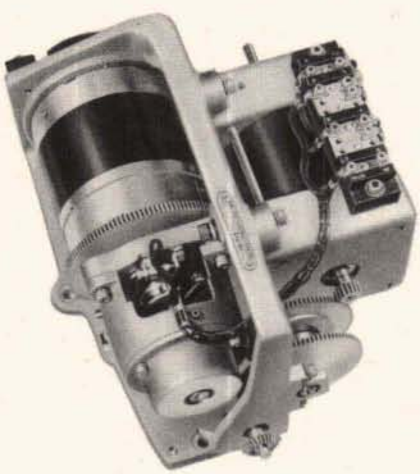
1 The coarse control keeps track of the number of revolutions the fine synchro turns.

2 The coarse control prevents the receiver from getting out of synchronism with the transmitter.

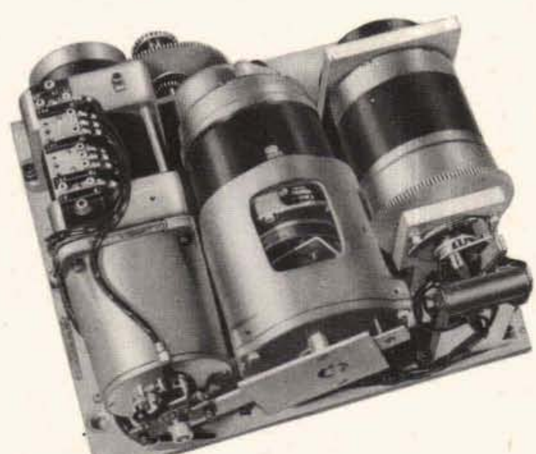
SYNCHRO RECEIVERS
using servo motors

Although synchro motors transmit extremely accurate signals, their outputs must be "boosted" considerably before they can drive heavily loaded shafts. The reason is that the torque delivered by a synchro falls off sharply as the rotor approaches the "point of synchronism." As the rotor nears the point of zero error, the induced current in the stator coils is rapidly reduced, seriously affecting the ability of the synchro to drive a heavy load. At the point of zero error, torque becomes zero.

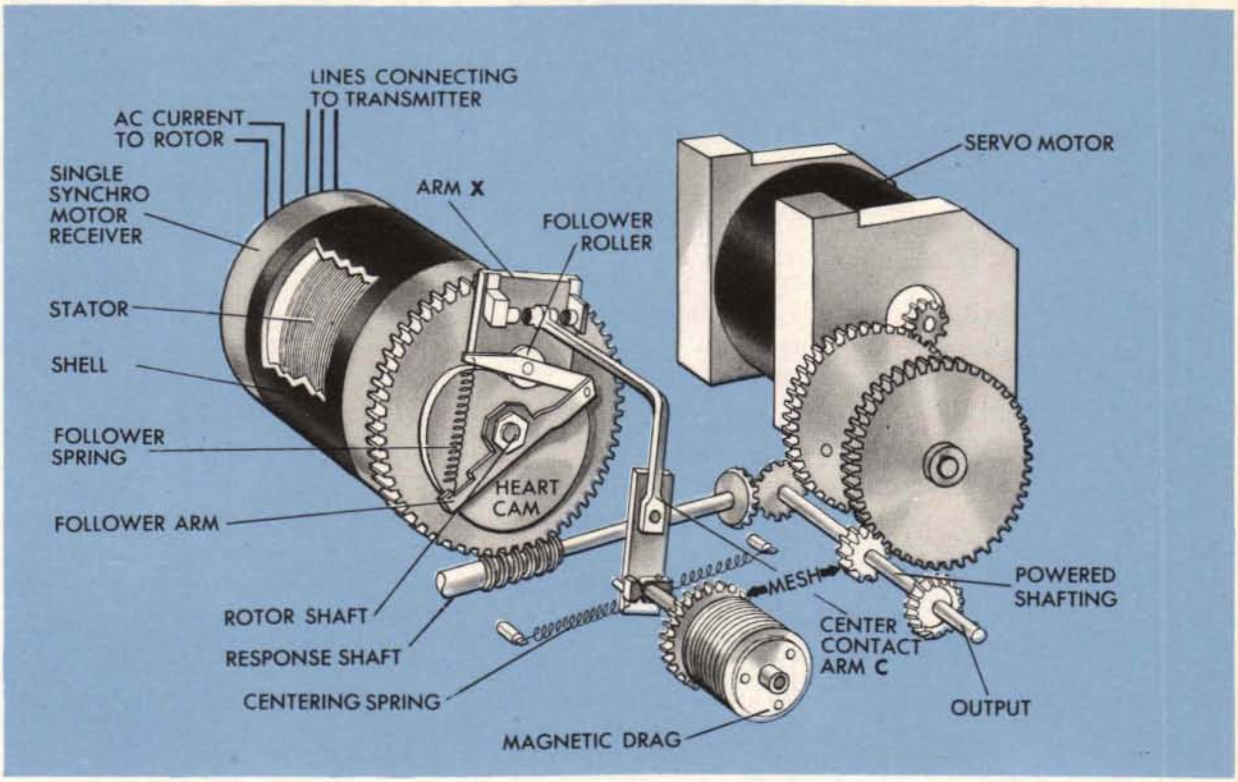
Accordingly, *synchro motors* are commonly used as *controls for servo motors* that drive the actual shaft load. Such synchro-servo combinations are known as Synchro Receivers. There are two types: single speed and double speed. The double speed unit provides fine and coarse control.



SINGLE SPEED RECEIVER WITH SERVO MOTOR



DOUBLE SPEED RECEIVER WITH SERVO MOTOR



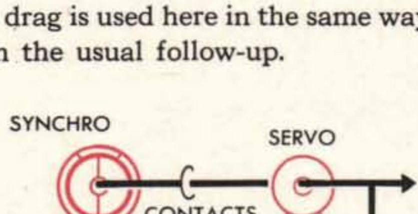
The **SINGLE** SPEED receiver

The contacts controlling the action of the servo are similar to those of a follow-up control.

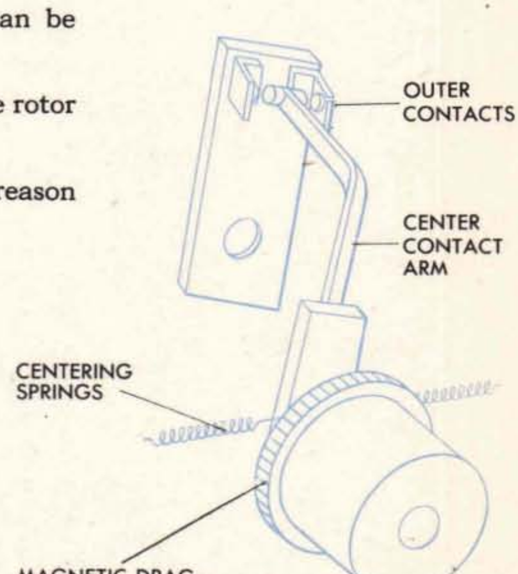
The two outer contacts are fixed on an arm which can be rotated.

The center contact is mounted on an arm attached to the rotor of a magnetic drag which is driven by the servo.

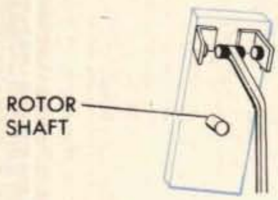
The drag is used here in the same way and for the same reason as in the usual follow-up.



THIS IS A SIMPLIFIED SCHEMATIC REPRESENTATION OF THE SINGLE SPEED RECEIVER

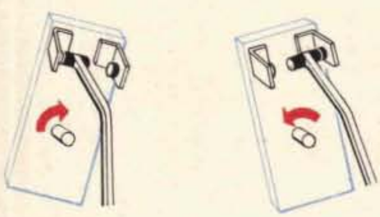


How the CONTACTS work



To understand how these contacts are controlled, first assume that the outer contact arm is fixed to the rotor shaft of the synchro motor.

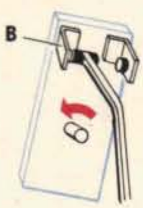
Making the contact



Assume that the rotor has turned in response to a transmitted signal, until one outer contact or the other is brought against a center contact–depending upon the direction taken by the rotor.

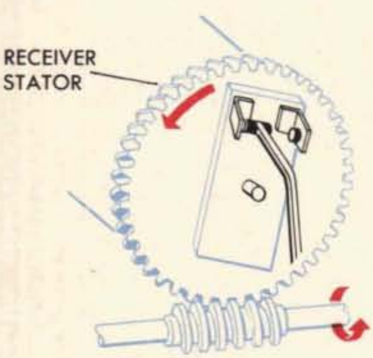
Breaking the contact

A way must now be found to separate the contacts once the servo has obeyed the signal. This can easily be accomplished by turning the rotor back in the direction from which it started.



For example, if the rotor were turned so as to make an electrical connection with the outer contact *B*, it would have to be turned back as indicated by the red arrow in order to break the contact.

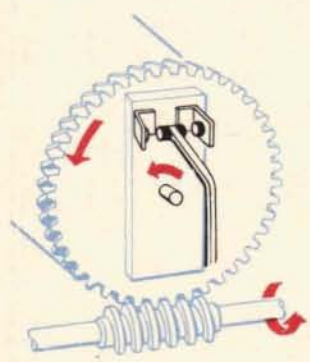
Why the Stator is turned



Since the rotor has been positioned in accordance with the transmitted signal, a means must be found to turn the rotor back without altering the signal value.

But the rotor of a synchro always tends to maintain its position relative to the receiver stator coils, no matter how much the stator may be rotated. The rotor may be turned back as much as necessary, without disturbing the signal value, *simply by rotating the stator.*

Turning the stator

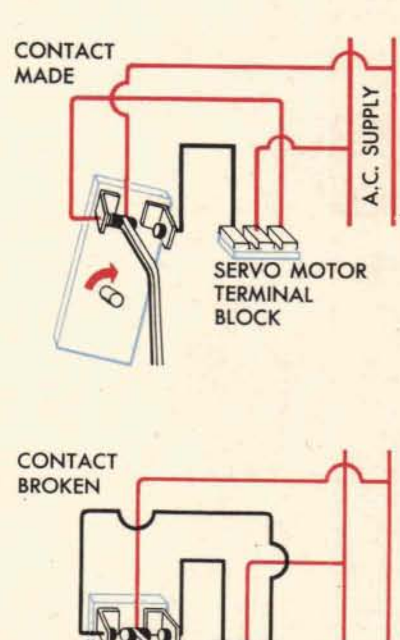


The motor stator, therefore, is geared to the "response" shaft of the servo, and the whole stator is rotated in the opposite direction to that taken by the rotor.

This means that AS THE STATOR OF THE SYNCHRO MOTOR IS ROTATED BACK, THE ROTOR, KEEPING ITS POSITION IN RELATION TO THE STATOR, IS ROTATED BACK ALSO. IN THIS WAY, THE OUTER CONTACT ARM IS BROUGHT BACK TO ITS CENTER POSITION WITHOUT DISTURBING THE POSITION OF THE ROTOR IN RELATION TO THE STATOR.

The receiver is like a FOLLOW-UP

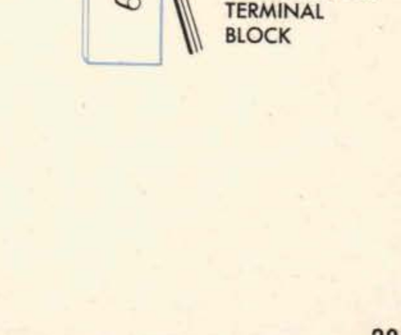
The Synchro Receiver, then, is a device which can operate like a follow-up control. In fact, it is often referred to as a "synchro follow-up."



Why the servo drives

When the rotor of the synchro motor revolves, contact is made between an outer and the center contact, and the servo drives.

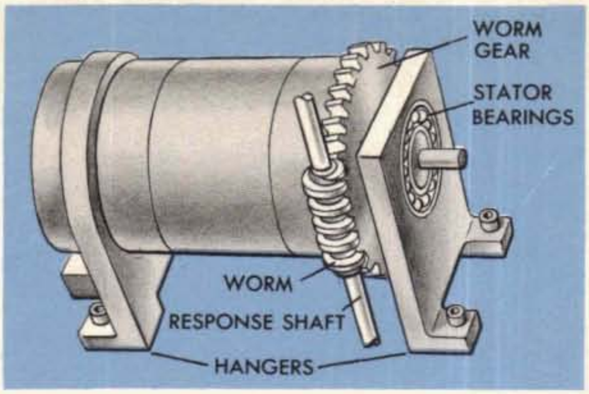
When the synchro stator is rotated back by the servo response, the contacts are separated and the servo ceases to drive.

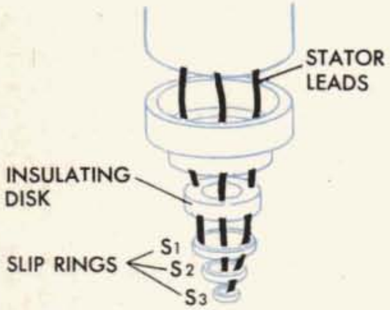


Special connections are needed

When a synchro stator must be rotated, a "Bearing-mounted Synchro Motor" is used. This type of synchro motor is provided with a slip ring and brush assembly to transfer the electrical circuits from the stationary frame to the rotating synchro motor.

The BEARING-MOUNTED SYNCHRO MOTOR





The rotor and stator are mounted so that both can turn

The synchro motor, with its stator bearings, is mounted in hangers.

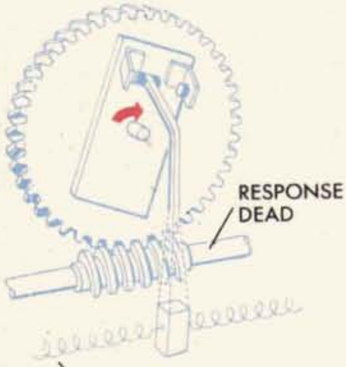
The rotor is positioned by a signal from the transmitter. The stator is turned by a worm and worm gear, driven by the servo response.

The stator leads pass through the one end cap, then through an insulating disk, and finally to the slip rings *S1*, *S2*, and *S3*, where they are secured. When the end cap is assembled, the slip rings are fastened to the insulating disk, and the disk to the end cap. The rotor leads are connected to two slip rings on one end of the rotor shaft.

One brush contacts each slip ring

Three brushes, marked *S1*, *S2*, and *S3*, bear against the stator's slip rings. Two brushes, *R1* and *R2*, bear against the slip rings on the rotor shaft. All five brushes are mounted on a terminal block and so connected that signals can be transmitted to the receiver on the three stator leads while leaving the stator at all times free to turn. 115-volt A.C. can be fed to the rotor in the usual way without interfering with the stator's freedom to turn. The terminal block and brush assembly are mounted on the stationary hanger.

The purpose of the heart cam



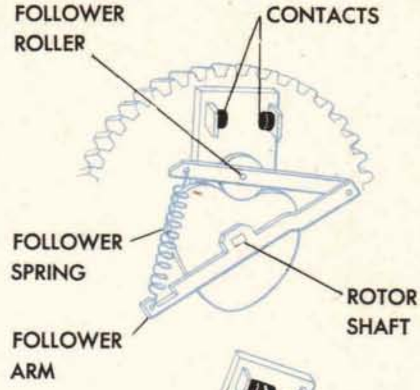
Suppose that a signal causes the rotor of the synchro motor to turn *while the power to the servo* is shut off.

In this case, contact would be made between an outer and a center contact, but would not be broken (for the servo's response is dead).

The synchro rotor would turn, rotating the outer contact arm against the center contact arm, and possibly damaging the contacts.

To prevent this, the arm carrying the outer contacts is *not* attached directly to the rotor shaft, but is fixed to a "heart cam." This heart cam is ball-bearing-mounted on the rotor shaft, so that it can turn freely.

The CAM at work



A follower arm, with a follower roller and a spring, is keyed to the end of the synchro motor's rotor shaft. The spring keeps the follower roller seated firmly in the "valley" of the heart cam.

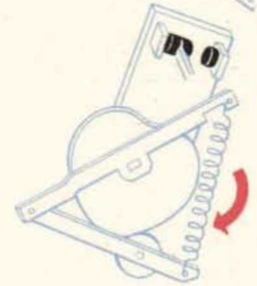
Whenever the rotor is turned by an incoming signal, the follower arm must turn, because it is keyed to the rotor shaft. As the follower arm turns, the follower roller is pulled around. The roller, being firmly seated in the valley of the cam, pulls the cam around. When the cam is rotated, an outer contact is brought against the center contact, and the servo starts to drive.

The rotor can continue turning after the contact is made

As the signal continues to come in from the transmitter faster than the servo can drive, the rotor of the synchro motor continues to turn and carry the follower arm around with it. The follower roller is now forced up and out of the valley, and rides around the heart cam (pressed to the side of the cam by the action of the spring).

So although an outer contact is now held firmly against the center contact, *the rotor is still free to turn.*

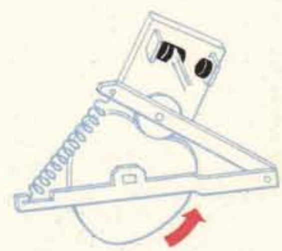
Now the rotor can turn until the follower roller reaches the peak of the cam *without disturbing the contacts.*



This means that if the servo power is shut off, a considerable input can be transmitted to the synchro receiver without throwing the system out of synchronism. In other words, the heart cam carries out the job performed by the intermittent gearing in other types of follow-up controls.

If the follower roller goes over the peak of the cam, the receiver will be out of synchronism with the input and will have to be re-set.

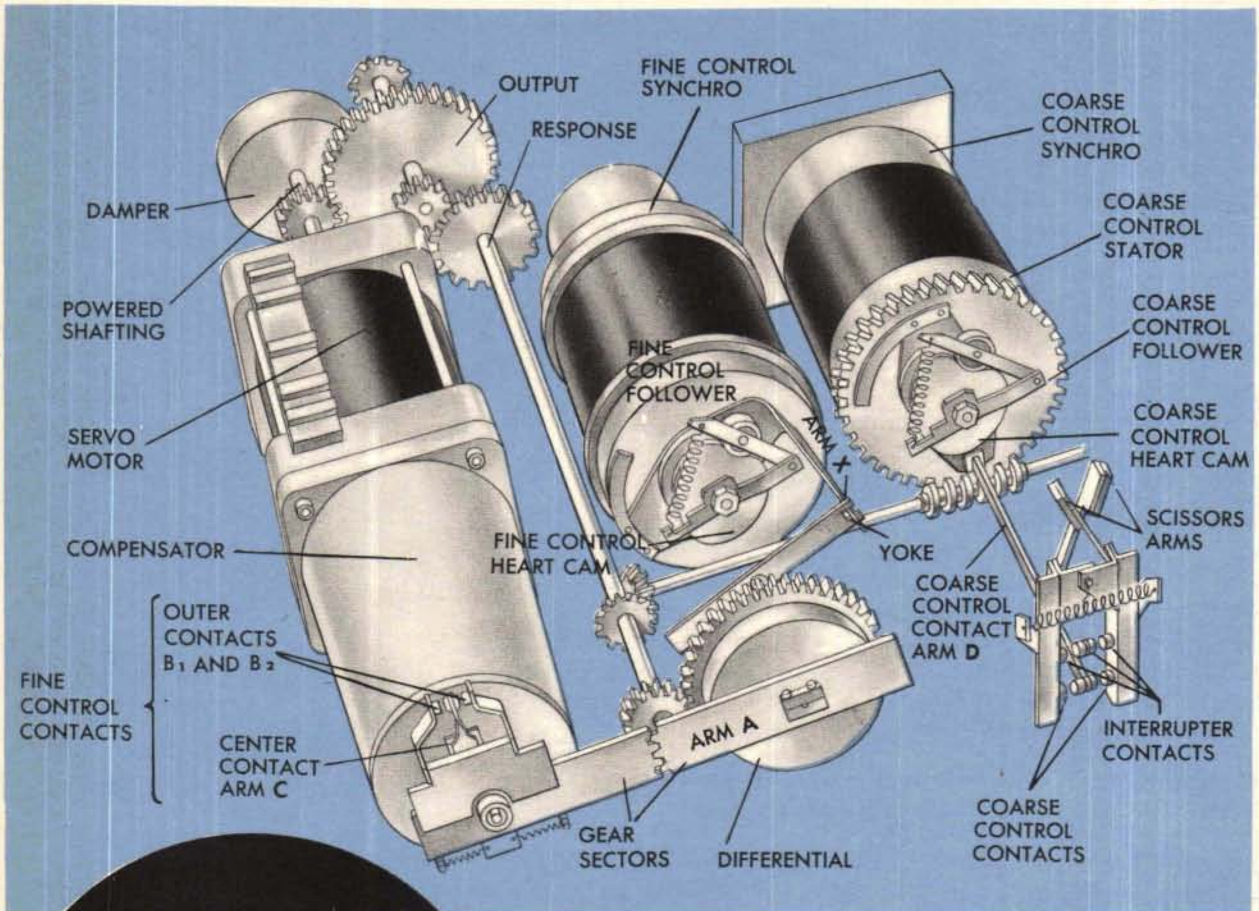
The rotor stays in the correct relationship to the stator



When the stator of the synchro motor is rotated, the rotor is turned back toward the position from which it started, and the follower roller becomes again seated firmly in the valley of the heart cam through action of the follower spring. The contacts are not yet separated, so the servo keeps driving the stator around.

As the rotor is turned still farther, the heart cam is moved around by the follower arm. The contacts separate, and the servo ceases to drive.

The DOUBLE SPEED receiver



In the double speed receiver, two synchro motors are used. One of these is connected to the coarse generator, and the other to the fine generator of a double speed transmitter.

Each synchro motor operates contacts which can control the action of the receiver's servo motor.

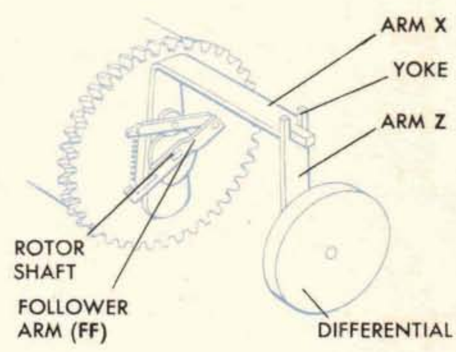
The fine and coarse synchro motors, however, cannot control the servo at the same time (except for a small interval when the coarse is taking over complete control from the fine). When the coarse synchro motor is in control, the contacts of an "interrupter," mounted on the scissors arms, are separated. Separation of the interrupter contacts breaks the circuit connecting the fine control contacts to the servo.

Normally, whenever the receiver is following a signal, the fine synchro motor controls the servo motor. If, for any reason, the output of the receiver is considerably out of synchronism with the input signal, the coarse synchro motor takes over control of the servo. The servo then drives, under coarse control, until the fine response (Arm X) is within approximately ⅓ of a revolution of its synchronized position.

In most double speed receivers the fine synchro rotor has a value per revolution of 10°. The coarse synchro takes control only when the output is more than about 3° (⅓ of a revolution) out of synchronism with the input signal.

How the FINE control operates

Upon receiving a signal from the transmitter, the fine control rotor turns.



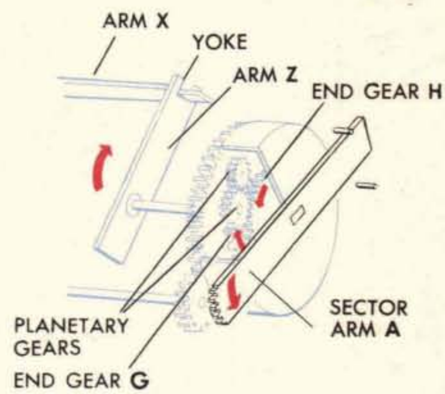
The follower arm, *FF*, which is keyed to this rotor, also rotates.

Behind the follower is the heart cam, ball bearing mounted and free to turn on the rotor shaft. The metal arm, *X*, is fixed to the heart cam.

As the follower arm rotates, with the follower roller firmly seated in the valley of the cam under spring pressure, it pulls the cam around with it.

Arm *X* fits into a yoke in arm *Z*.

As arm *X* rotates, it rotates arm *Z*.



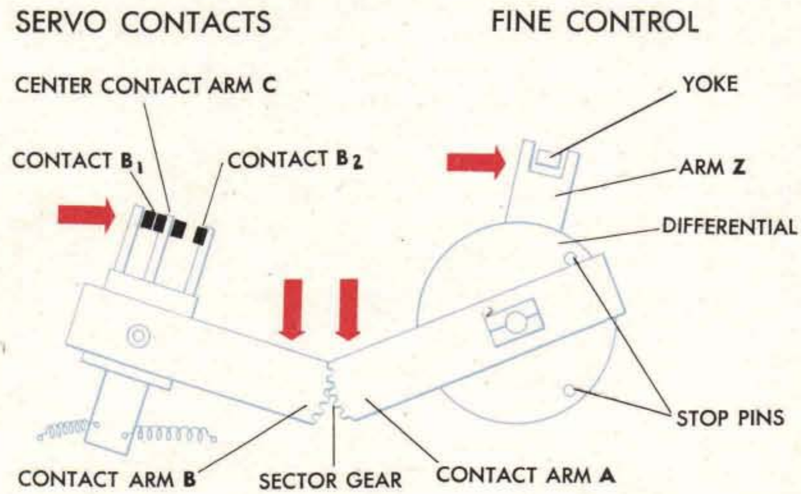
Arm *Z* is connected to end gear *G* of the differential. As *Z* rotates, it turns this gear.

As gear *G* rotates, through the planetary gears of the differential, it rotates the other end gear, *H*.

End gear *H* is connected to sector arm *A*. As gear *H* rotates, arm *A* rotates.

In this way, the rotation of the fine synchro rotor causes arm *A* to rotate.

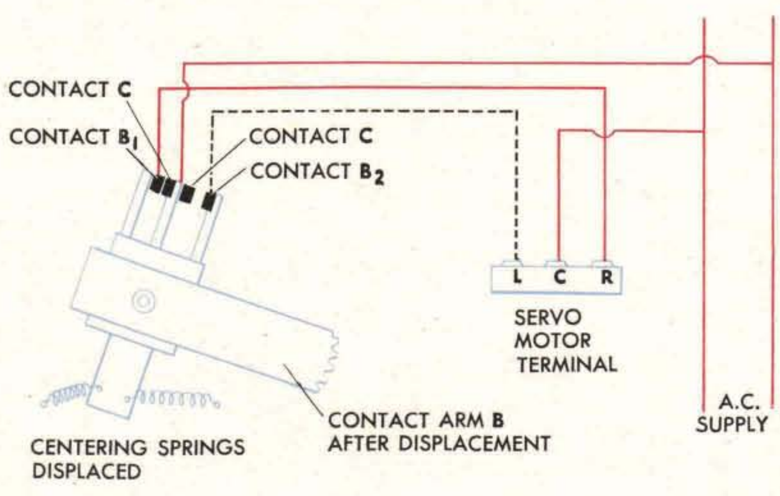
How the FINE control operates (continued)



Arm *A* will move until it closes the contacts. The stop pins limit the rotation of arm *A* and so prevent it from moving out of mesh with arm *B*.

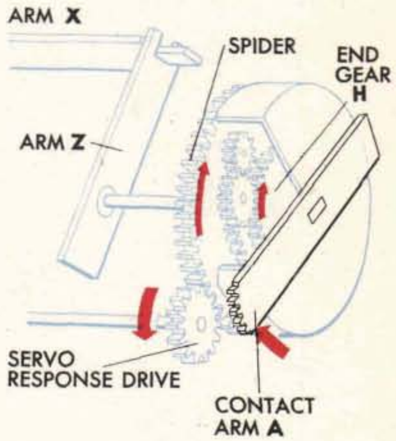
As arm *A* rotates, contact arm *B* is moved from its center position. This brings one of the outer contacts, *B1* or *B2*, mounted on arm *B*, against the center contact.

Closing the contacts completes a circuit to the servo motor, and the servo drives.



If contact is made between *B1* and *C*, the servo drives in one direction. If contact is made between *B2* and *C*, it drives in the opposite direction.

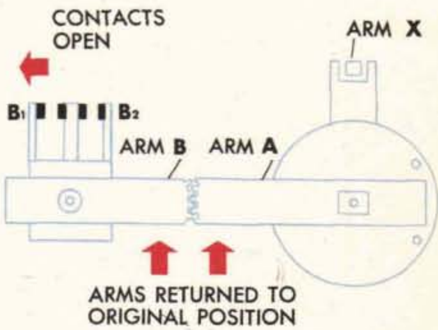
The servo motor is geared to the spider of the differential so that when the servo drives, the spider of the differential is rotated. This rotation causes the differential end gear *H* to turn in a direction which tends to move arm *A* back to its original or synchronized position.



The position of arm *A* at any instant corresponds to the difference, or "error," between the output of the fine control receiver and the output of the servo. When the point of synchronism is reached, there is no error. Contact arm *A* is back again in its original position, centered between the stop pins. This means that the contacts are separated, and the servo ceases to drive.

Here's a quick run through the fine control

1. The rotor of the fine synchro motor turns and rotates arm *A*. This displaces contact arm *B*, and contact is made between an outer and an inner contact.
2. The servo drives the output shafting, which positions whatever computer mechanism is involved, and also rotates the spider of the differential.
3. Rotation of the differential spider rotates arm *A away* from the stop pin, back towards the position from which it started.
4. When the output of the servo motor equals the output of the fine control synchro, arm *A* is again back in its original position, centered between the stop pins.
5. Now the contacts are separated, and the servo stops driving.



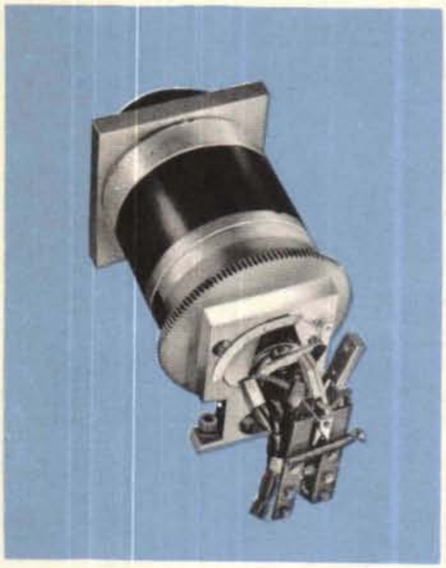
NOTE: When the coarse synchro motor is in control, contacts *B1* and *B2* will also close and open, but their movement will have no effect upon the action of the servo.

When the coarse synchro motor is controlling the servo, the response shaft, being geared to the servo, continues to drive the spider of the differential. This means that the response "backs out" through the differential and causes arm *X*, on the fine control synchro, to be rotated. When this occurs, the contacts of the fine control (*B1* and *B2*) are closed and opened according to the direction in which arm *X* is rotated.

However, when the coarse synchro is in control, the fine control circuit is broken at the interrupter, and no current can flow to the fine contacts.

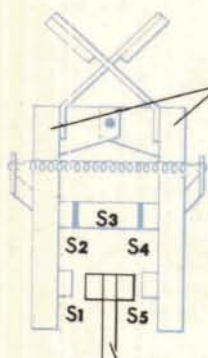
The closing and opening of these contacts, therefore, has no effect upon the action of the servo.

The COARSE control operation



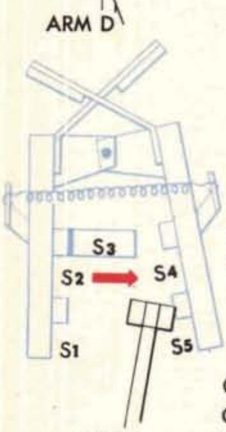
The coarse control does two jobs.

1. By opening the interrupter contacts it takes control away from the fine control contacts. It does this whenever the error between the signal and the response becomes too large for the fine control to handle.
2. By positioning the coarse contacts it then controls the servo motor. The servo motor drives to reduce the error between the signal and the output. When the error is reduced the interrupter contacts close and the fine control contacts take control.



A close-up of the contacts

Contact arm *D* and the scissors arms form a double pole switch. Contact arm *D* is positioned by the coarse synchro rotor through the heart cam. When the scissors arms are in their normal position, contacts *S2, S3, and S4* of the interrupter are closed. This completes the fine control synchro circuit to the servo motor. Contact *S3* is fixed and insulated from the frame.



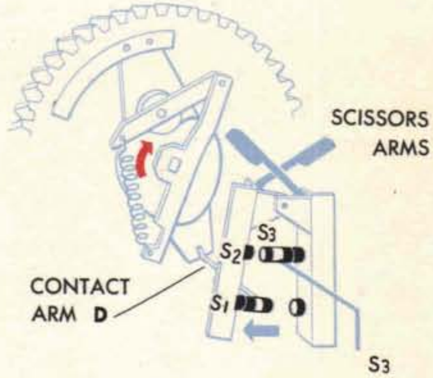
When contact arm *D* is rotated against contact *S5*, the pressure exerted by arm *D* displaces one scissors arm, and the contacts *S3* and *S4* are separated, breaking the circuit through which the fine control synchro motor controls the servo.

But as contact arm *D* presses against *S5*, another circuit to the servo is completed. Through this new circuit the *coarse* synchro motor controls the servo motor.

The coarse synchro takes over control. The fine control synchro is automatically cut out. When the contact is made between arm *D* and contact *S1*, the servo motor is driven in the opposite direction by the *coarse* control synchro, and the fine control circuit is broken by the separation of *S2* and *S3*.

How coarse control works

If the receiver is out of synchronism with the transmitter by a considerable amount the following action takes place:



1 When a signal is received from the transmitter, the coarse control rotor is rotated.

2 The heart cam, ball-bearing-mounted and free to turn on the rotor shaft, is pulled around by the follower, with the roller in the valley of the cam.

3 Contact arm *D,* being fixed to the heart cam, is rotated and brought against *S1*, on a scissors arm.

4 This starts the servo.

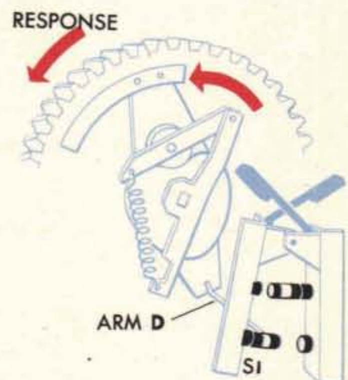
5 As contact arm *D* is brought against *S1* the scissors arm to which *S1* is fixed is displaced, and contacts *S2* and *S3* are separated.

6 When *S2* and *S3* are separated, the fine synchro takes no part in the control.

7 After the scissors arm is displaced a short distance, it comes against a stop pin.

8 But the rotor of the coarse synchro motor continues to rotate in accordance with the signal.

9 The heart cam follower, being keyed to the rotor shaft, continues to turn with the rotor, and the follower roller is forced up and out of the valley of the cam and rides down the slope of the cam. The scissors arm remains displaced.

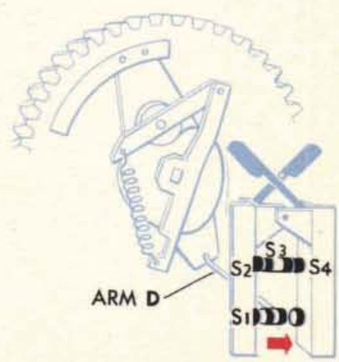


10 The stator of the coarse synchro motor is rotated by the servo response shaft, in the opposite direction to that taken by the rotor.

11 The rotor, keeping its position with respect to the stator, is brought back until the roller is once more seated in the valley of the heart cam.

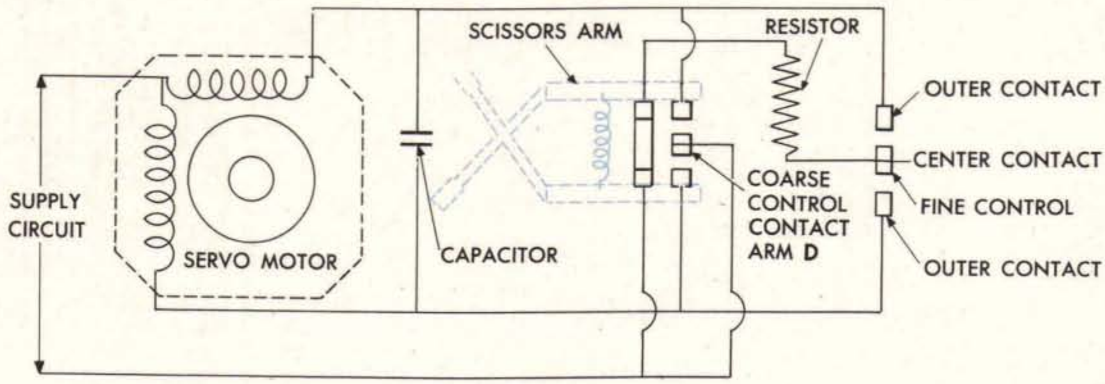
12 However, contact arm *D* is still pressed against *S1*.

13 The servo continues to drive and rotate the stator of the coarse synchro motor until contact arm *D* is separated from *S1*, and the circuit operated by the coarse control synchro is broken.

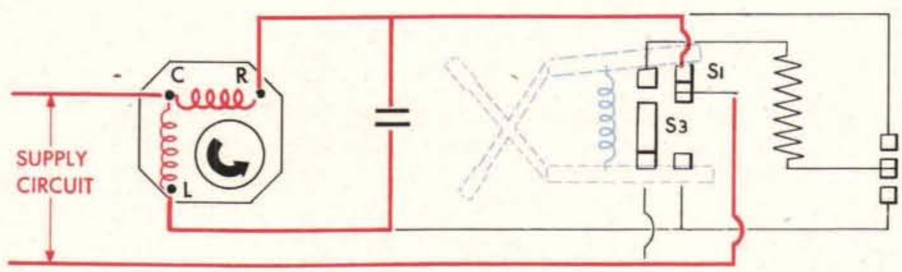


14 As contact arm *D* separates from *S1*, the contacts *S2* and *S3* are held together by the spring between the scissors arms—completing the circuit which gives control to the fine synchro motor. Contact arm *D* of the coarse motor always breaks the circuit through *S3* before the rotor of the fine control synchro motor has turned sufficiently to cause the follower roller to be driven over the peak of the fine heart cam. In this way the coarse control keeps the mechanism from getting out of synchronism with the generators of the transmitter.

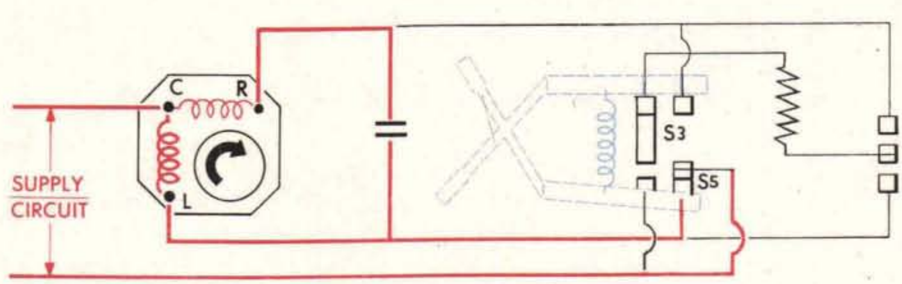
WIRING DIAGRAM



Here is the wiring for the double-speed receiver. Neither the coarse control nor the fine control is shown in operation; the servo motor is at rest.

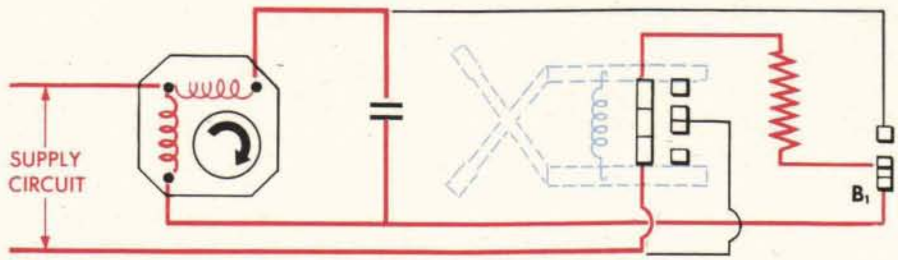


When the contact arm of the coarse synchro motor is rotated against *S1* on the scissors arm, fine control contacts are eliminated, because the circuit through *S3* is broken, and the servo drives in one direction.

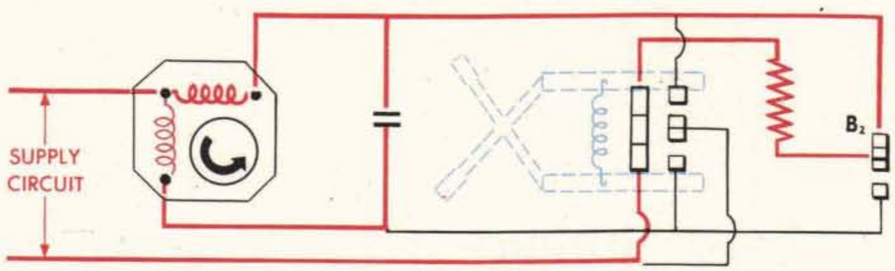


When the contact arm of the coarse synchro motor is rotated against *S5* on the scissors arm, fine control contacts are also eliminated, because the circuit through *S3* is broken, and the servo drives in the opposite direction.

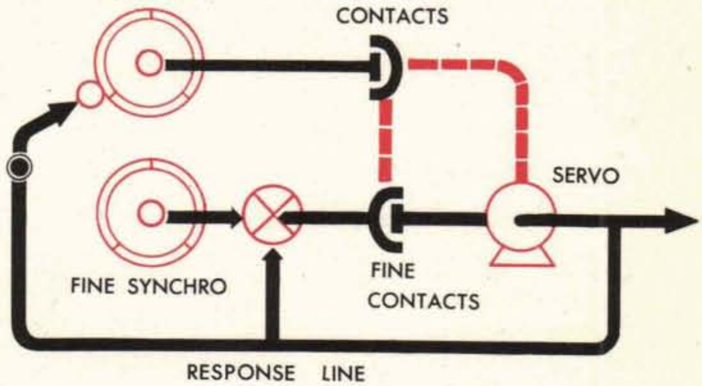
for the double speed receiver



When the contact arm of the coarse control synchro motor is centered, and outer contact *B1* is brought against the center contact arm by the fine control synchro motor, the servo drives as indicated.



When the contact arm of the coarse control synchro motor is centered, and outer contact *B2* is brought against the center contact arm by the coarse control synchro motor, the servo drives in the opposite direction.



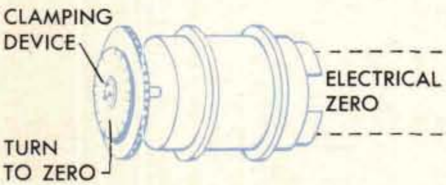
DOUBLE SPEED TRANSMITTER

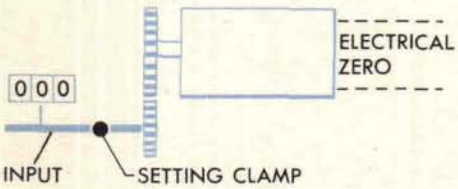
Setting TRANSMITTERS

A *transmitter* is a synchro unit having a mechanical input and electrical output; a *receiver* is a synchro unit having an electrical input and a mechanical output.

The purpose when setting is to join the inputs and the outputs so that the electrical and mechanical systems are in agreement.

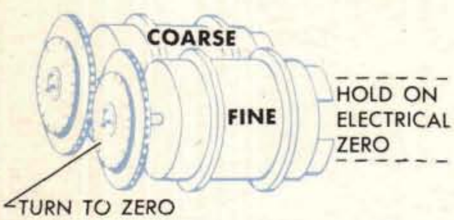
This agreement is reached by using the electrical zero position of the synchro as the reference point when joining the electrical and mechanical signals.

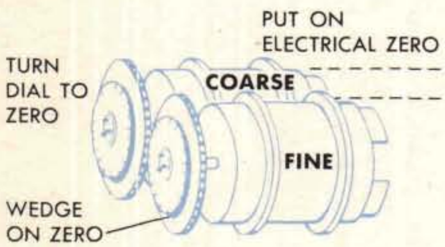


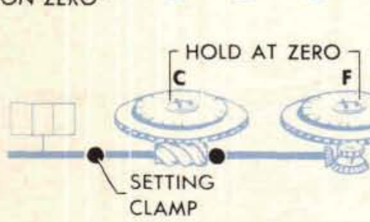


To set a **SINGLE** SPEED TRANSMITTER

1. Put the synchro transmitter on electrical zero.
2. Turn the dial of the synchro transmitter until it reads zero.
3. Tighten dial clamping device.
4. Holding the synchro transmitter dial at zero, put the input counter on zero.
5. Tighten the setting clamp.
6. Disconnect all test wires.



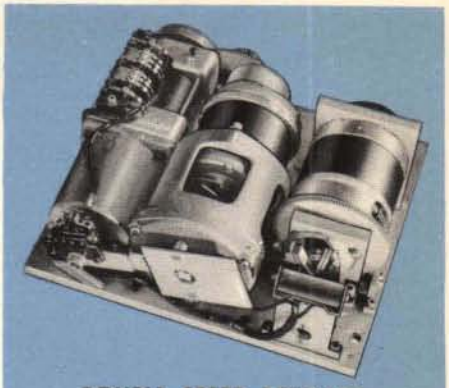




To set a **DOUBLE** SPEED TRANSMITTER

1. Put the FINE transmitter on electrical zero.
2. Holding the FINE transmitter on electrical zero, turn its dial until it reads zero.
3. Tighten the dial clamping device.
4. Wedging the FINE dial at zero, put the COARSE transmitter on electrical zero.
5. Holding the COARSE transmitter at electrical zero, turn its dial to zero.
6. Tighten the dial clamping device.
7. Tighten the clamp controlling the FINE to COARSE setting.
8. Holding both transmitters at their zero positions, turn the input counter until it reads zero.
9. Tighten the setting clamp.
10. Remove the wedge.
11. Disconnect all test wires.

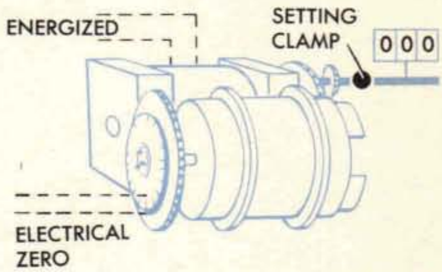
and RECEIVERS



DOUBLE SPEED RECEIVER

To set a SINGLE SPEED RECEIVER

1. With the synchro motor on electrical zero, energize the servo motor. It will synchronize at zero.
2. Turn the output counter until it reads zero.
3. Tighten the setting clamp.
4. Disconnect all test wires.



To set a DOUBLE SPEED RECEIVER

1. Put the FINE synchro motor on electrical zero.
2. With the FINE synchro on electrical zero, turn the motor shafting to centralize the FINE contacts.
3. Wedge the motor shafting at its zero position.
4. With the COARSE synchro on electrical zero, centralize the COARSE contacts by slipping the worm on the shaft driving the coarse synchro.
5. Tighten the clamp controlling the COARSE to FINE setting. This clamp is on the worm gear.
6. Remove the wedge from the shafting.
7. Energize the servo motor. It will synchronize at zero.
8. With both synchros on electrical zero and the servo motor energized, turn the output counter until it reads zero.
9. Tighten the setting clamp.
10. Disconnect all test wires.